OPERATIONAL STORAGE
OF
SANTA CLARA VALLEY
GROUNDWATER BASIN

March 1999

Santa Clara Valley Water District

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OPERATIONAL STORAGE OF SANTA CLARA VALLEY GROUNDWATER BASIN

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March 1999

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Table of Contents

Page

Executive Summary 1
Background 2
Model Analysis........ 7
Model Results........ 12
Key Findings 16
Further Studies 17
Appendix A 19
Appendix B 26
Appendix C 30
References 38

Figures

Figure..Page

1 Santa Clara Valley..2
2 Santa Clara Valley Groundwater Basin 3
3 SYSMOD/GMOD Integration 8
4 SYSMOD vs. GMOD Natural Recharge 11
5 Groundwater Storage for Santa Clara Valley Basin................................ 12
6 Simulated Groundwater Elevation 13
7 Low Groundwater Levels (1977)-Depth to Water 14
8 High Groundwater Levels (1983)-Depth to Water 15
9 Location of the Wells 19
10 Central Subbasin-Confined Zone 20
11-12 Central Subbasin-Forebay Zone 21
13 East Subbasin-Confined Zone 22
14 East Subbasin-Forebay Zone 22
15-19 West Subbasin-Confined Zone.. 23-25
20 West Subbasin-Forebay Zone 25
21 Cumulative Groundwater Storage 26
22 1977 Groundwater Pumping Distribution 27
23 Basin Groundwater Pumping 28
24 Basin Natural Recharge... 28
25 Basin Artificial Recharge 29
26 Central Subbasin Exchange... 30
27 East Subbasin Exchange.. 30
28 West Subbasin Exchange 31
29 Central Subbasin Groundwater Pumping 32
30 East Subbasin Groundwater Pumping.. 33
31 West Subbasin Groundwater Pumping 33
32 Central Subbasin Total Recharge Comparison 34

Figure .... Page

33 East Subbasin Total Recharge Comparison 34
34 West Subbasin Total Recharge Comparison 35
35 Central Subbasin Groundwater Storage Comparison 36
36 East Subbasin Groundwater Storage Comparison 36
37 West Subbasin Groundwater Storage Comparison 37

EXECUTIVE SUMMARY

The Santa Clara Valley Water District was created by the state legislature to provide water supplies for the county and to manage these multiple sources of water supplies. These supplies are stored in the groundwater basins as well as in surface reservoirs when abundant and withdrawn from storage when supplies are not sufficient to meet the demands. The Santa Clara Valley Groundwater Basin historically has supplied approximately half of the total water use in the North County. This report documents the investigations that have been conducted to determine the amount of water that can safely be withdrawn and stored - the operational storage capacity – in the Santa Clara Valley basin.

To address the potential water supply shortages, and to ensure a reliable supply of high quality water through the year 2020, the District started the Integrated Water Resources Plan (IWRP) in 1996. One of the elements in the preferred strategy of the IWRP is the groundwater basin's ability to store water in wet years for use in the later drier years. This component of the groundwater basin storage capacity is referred as the operational storage. The operational storage capacity of the Santa Clara Valley groundwater basin for the IWRP was estimated to be *250,000* ac-ft; however, this operational storage was based on a static analysis.

The dominating criterion for the operational management of the groundwater basin is land subsidence. The operational storage of the groundwater basin computed for this analysis was performed using a deterministic approach and links the System Simulation Model (SYSMOD) with the Groundwater Model (GMOD). The historical hydrology used was from 1967 to 1996 which includes two severe periods of drought. The iterative process of using these two models resulted in a solution based on the current policies and programs that guide the operation of the utility.

Key Findings from this analysis are:

- The operational storage capacity of the Santa Clara Valley Basin is estimated to be 350,000 acre-feet.

- The rate of withdrawal from the basin is a controlling function and pumping should not exceed 200,000 acre-feet in any one year. Current basin operation does not exceed this limit.

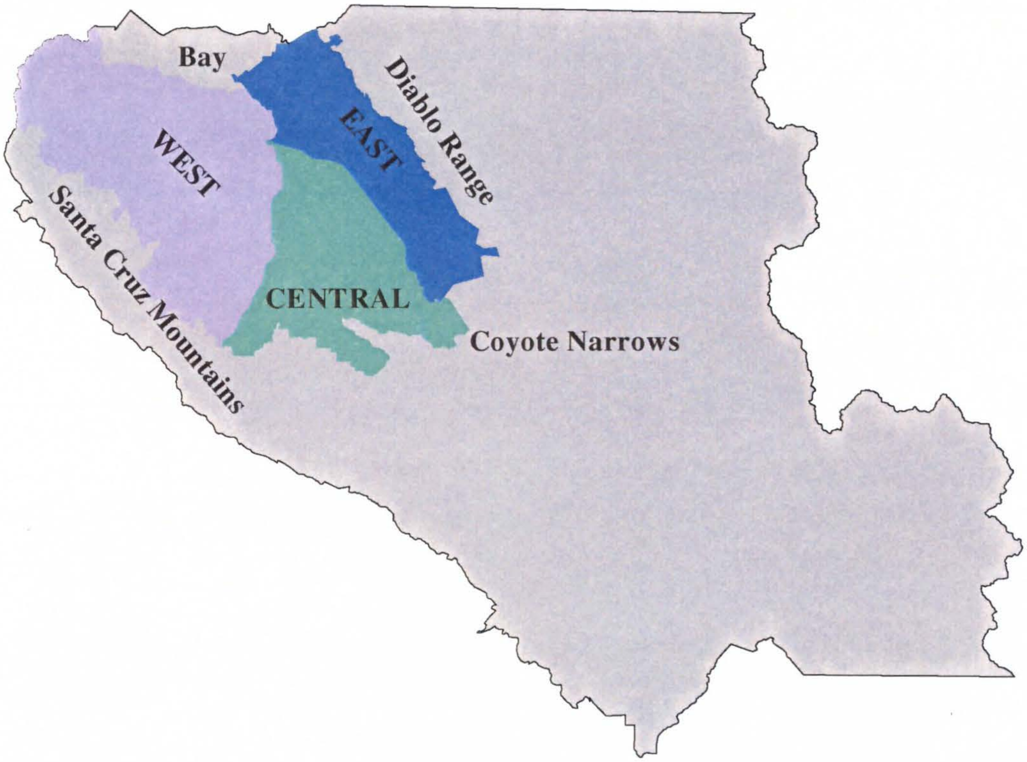
- The west subbasin is operationally sensitive which requires the Rinconada Water Treatment Plant to receive the highest priority when supplies become short.

BACKGROUND

The Santa Clara Valley Water District was created by the state legislature to provide a supply of water, adequate in quantity and quality, needed to meet the desired quality of life in the community. An important aspect to complete this mission is to manage the multiple sources of water supplies and store these supplies when abundant and to withdrawal from this storage when supplies are short. This requires the District to manage the groundwater supplies and determine the amount that can be withdrawn or stored safely, the operational storage capacity of the basin. The primary groundwater storage capacity is in the Santa Clara Valley groundwater basin and this report documents an investigation of this basin's storage.

The Santa Clara Valley groundwater basin extends from Coyote Narrows at Metcalf Road to the county's northern boundary. The basin is bounded on the west by the Santa Cruz Mountains and on the east by the Diablo Range; these two ranges converge at the Coyote Narrows to form the southern limit of the basin. The basin is 22 miles long and 15 miles wide, with a surface area of 225 square miles. The basin is further divided into three water supply planning subbasins: West, Central and East as shown in *Figure 1.*

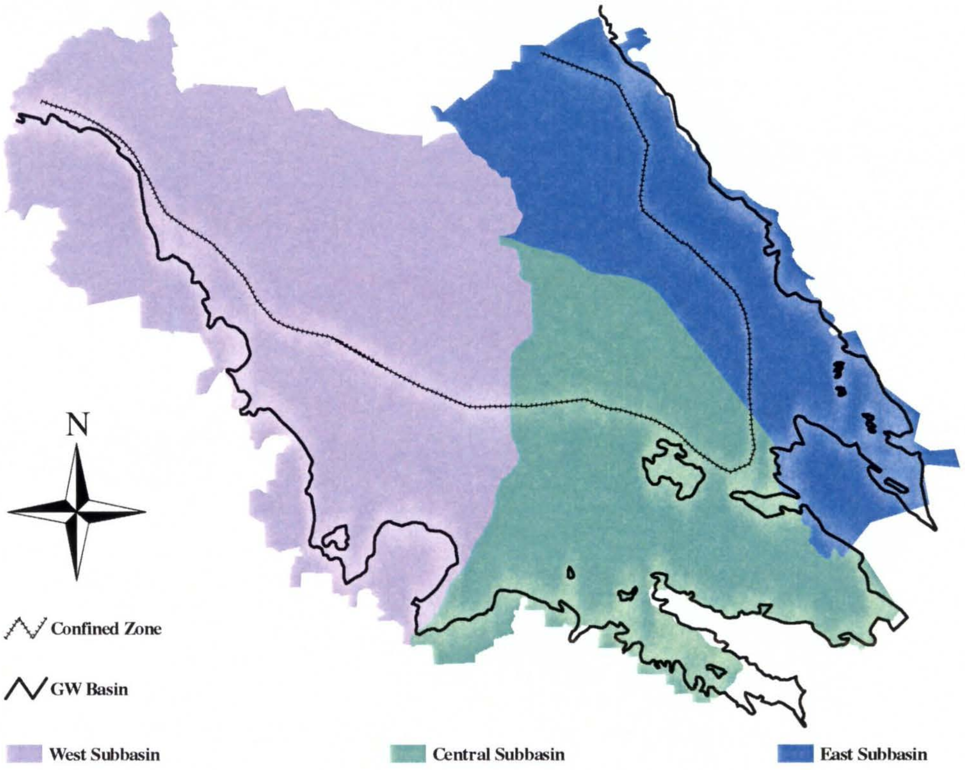
Figure 1: Santa Clara Valley



The Santa Clara Valley Basin historically has supplied approximately half of the total water use in the zone of benefit (W-2) that encompasses this area of the county. The District's conjunctive use program relies on the basin to treat raw water from the District's recharge operations and convey it to areas where the water is being pumped from local wells. The basin also acts as an underground reservoir, storing water when supplies are plentiful and allowing this stored water to be used during dry periods.

A confined zone within the northern area of the basin is overlaid with a zone of interbeded clay lenses deposited as bay mud during interglacial periods when the sea level stood at a higher elevation than at present as shown in *Figure 2*.

Figure 2: Santa Clara Valley Groundwater Basin



There have been several investigations in the past to determine the total storage capacity and the operational storage capacity of the groundwater basin. These investigations have used different methodologies and tools and are summarized below.

DWR's Estimate of Basin Storage

In 1955, the California Department of Water Resources (DWR) estimated the total storage capacity of North Santa Clara Valley to be 1,900,000 ac-ft (Bulletin No. 7).

In this study the Coyote basin was included in the estimates of the North Santa Clara Valley basin. DWR made their estimate by multiplying the average specific yield for the sediments (the amount of water that is released from the voids in the soil column for each unit drop in head), by the volume of material in the depth interval from 0 to 300 feet below ground surface. DWR refined this estimate by limiting the usable capacity to a depth interval between 25 to 200 feet below the ground surface. With this refinement, the total usable storage capacity for the Santa Clara Valley and Coyote Basins was estimated to be 1,200,000 ac-ft. However, this estimate did not take into account operational constrains such as land subsidence, which will recur if groundwater elevations drop below certain thresholds; nor did it consider high groundwater levels that may be a nuisance for structures that are below ground; nor did it consider the limitation on groundwater withdrawal because of available pumping capacity.

J.F. Poland on Subsidence

Since DWR's investigation, there has been additional work in the cause of subsidence in the Santa Clara Valley Basin. The late J. F. Poland with USGS led most of these subsidence investigations. The conclusion of these studies is that the subsidence in this area is attributed to the decrease in the artesian head (water levels above the top of the confining clay layer). Subsidence in our basin occurs when the water between the clay particles is removed and the sediments collapse. This has resulted in subsidence that started in 1916 and has dropped some areas of the ground surface by over 12 ft by 1967. By 1969, the artesian heads had recovered and the rate of subsidence decreased from 1 ft/yr. in 1961 to .01 ft/yr. in 1973. In 1976, J. F. Poland concluded that if the artesian head can be maintained 10 to 20 ft above the levels that occurred in 1971-73, subsidence will never recur. But, if the artesian head is drawn down 20 to 30 ft below the 1971-73 levels, subsidence will likely recommence. From the historical drops in land surface and the resultant damage to infrastructures, subsidence is the major limiting factor in determining the operational storage capacity of the basin.

Storage Capacity - Static Analysis

In 1990, District staff investigated the operational storage capacity for the Santa Clara Valley basin. In this study the operational storage was defined as the storage in the forebay area of the basin between a "full" level and a "subsidence threshold". The "full" condition was loosely defined as the storage corresponding to the highest elevation ever experienced in the basin. The "subsidence threshold" corresponded to the elevations below which subsidence may reoccur as defined by J. F. Poland. The operational storage capacity was defined as the volume of the water contained between "full" and the "subsidence thresholds". This was a static analysis in that one historical year was chosen to represent the "full" level and one historical year was chosen to represent the "subsidence" level. The difference in storage between these two historical years was then calculated as the operational storage capacity. This study resulted in a range of operational storage capacity from 130,000 ac-ft to 345,000 ac-ft depending on what years were chosen to constitute the "full" and "subsidence threshold" conditions. Choosing 1969 as the year that the groundwater levels would be above the "subsidence threshold" and 1983 as the year that the highest groundwater elevations were observed as the "full" condition, the operational storage was estimated to be 250,000 ac-ft. This estimate has been used in all of the system analysis investigations made in support of the Integrated Water Resources Plan (IWRP). But this operational storage capacity did not include the true dynamic nature of the basin. The observation made from this study was:

- The groundwater system is a dynamic one and therefore requires a dynamic analysis to determine the operational storage capacity of the basin.

Storage Capacity – Modified Static Analysis

In 1992, as part of the groundwater model development for the Santa Clara Valley basin, CH2M Hill re-investigated the operational storage capacity of the basin using the historical groundwater elevations and the subsidence levels. There were several refinements in this analysis compared to the previous analysis and differed from the previous one by incorporating the following:

- Because of the concerns of the District's Water Retailers, the Subsidence Threshold of .01 ft/yr as a tolerable rate of subsidence recommended by GEOSCIENCE Support Services was incorporated and these thresholds in the confined zone were interpolated to cover the entire confined area.
- Composite groundwater elevation maps were contoured using groundwater elevation data from 1930 to 1990.
- Groundwater storage estimates were computed for both the confined and the forebay zones.
- A refined grid was used to calculate the groundwater storage instead of the nodal map that was used by DWR.

The operational basin storage estimates ranged from 180,000 to 580,000 ac-ft, depending on which minimum and maximum groundwater surface was selected and how the groundwater elevations transitioned from the confined zone to the forebay zone.

At the time this work was being performed, the District's groundwater model (GMOD) was not yet calibrated and the entire analysis was based on the available high and low groundwater elevations. In this analysis, the volume of water in the groundwater basin between the minimum and maximum groundwater surface elevations was defined as the operational storage capacity.

Operational Storage Capacity - Dynamic Analysis

In 1994, GMOD was calibrated and District Staff used this model along with the established subsidence threshold rate of .01ft/yr to analyze the operational storage of the basin. This analysis was the first attempt to use the calibrated groundwater model to determine the operational storage capacity by considering the dynamics of groundwater flow movement and not a static process of calculating a volume between two groundwater elevations. This investigation defined the operational storage as the cumulative change in storage that occurs over the time frame of the analysis. A series of wet and dry hydrologic conditions with various water uses were modeled to achieve the high and low groundwater elevations. Simulation of these conditions resulted in a cumulative groundwater storage change ranging from 100,000 to 270,000 ac-ft. It became apparent that the results are highly dependent on the water use and hydrological conditions used. The observations made from this study were:

- Operational groundwater storage capacity is not a single number. Its value depends on how the basin is operated. There are many possible storage levels in the forebay when groundwater elevations reach subsidence thresholds in the confined zone.
- A conjunctive use system that requires a dynamic analysis of surface and groundwater deliveries is needed to determine operational storage capacity. The District's system simulation model (SYSMOD) which models the surface system deliveries and GMOD should be used in conjunction to determine the operational storage capacity of the basin using a deterministic approach.

MODEL ANALYSIS

The following section describes the modeling approach, the assumptions used, and the major problems encountered and how they were resolved. The current investigation relied on the findings of the previous studies and incorporated what was learned during those studies. The operational storage capacity is defined as the cumulative storage that the groundwater basin has experienced as a result of a specific operation over a period of time without initiating subsidence or causing high groundwater level nuisance that impact structures located below ground.

Modeling Approach

The analysis used a deterministic approach to evaluate the operational storage capacity of the basin. Deterministic modeling uses the historical hydrology and imposes water demands and operates with the utility's existing or proposed facilities. This approach eliminates the potential subjective biases in selecting the initial storage conditions and the water supply conditions used during the analysis. How many wet years? How many dry years? How wet? How dry? are not determined by the modeler.

The time period of the analysis is from 1967 to 1996 and was analyzed using a time step of 3 months. Two severe droughts occurred during this period; these were 1976-1977 and the recent 1987-1991 drought. The hydrological data for 1992-1996 was synthesized to duplicate the effect of a drought severity that occurred during the 1927-1934 dry period, the period that DWR uses as a basis for their firm yield for the State Water Project.

Groundwater Elevation Criteria

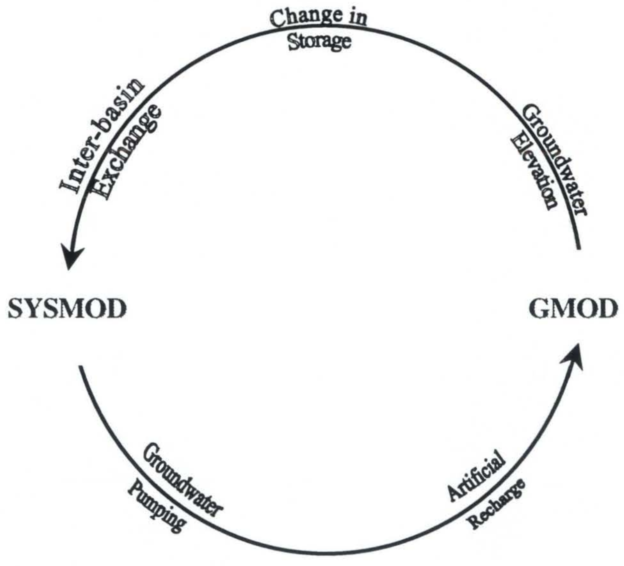
The dominating criterion for the operational management of the groundwater basin is land subsidence. Controlling subsidence has been the main concern that overshadows all other criteria in groundwater management in the Santa Clara Valley Basin. Working with the water retailers in developing GMOD, subsidence thresholds were established for ten index wells throughout the basin. After much discussion, the retailers requested that the rate of subsidence be equal or less than .01 ft/yr. This is the tolerable rate of the estimated subsidence rate in 1973 after subsidence was controlled. The subsidence thresholds were then established where the water level below these thresholds would indicate a subsidence rate of more than .01 ft per year. The basin was operated in such a manner that the groundwater elevations for these index wells did not fall below the thresholds.

For the areas of the basin that are in the forebay, the high groundwater levels may create undesirable conditions; such as, flooded basements. Hence, for the first pass of the analysis these high groundwater elevations were maintained at least 40 ft below the ground surface to minimize any nuisance conditions. However, in some areas of the basin the historical groundwater elevations were higher than 40 ft. below the ground surface. Therefore, to fully realize the basin storage potentials, the allowable high ground water elevations in these areas were changed to their historical maximum levels.

Modeling

The District's system simulation (SYSMOD) and groundwater numerical (GMOD) models were used to determine the storage changes and water levels that the groundwater basin will experience with the year 2020 water demands imposed. GMOD was used to evaluate the groundwater basin and SYSMOD was used to evaluate the system-wide operation of the utility over the historical hydrology. However, SYSMOD must assume a storage capacity for the groundwater basin before it simulates the system-wide operation and balances the demand with the supplies. As a result, an iterative process was needed in which data from SYSMOD was inputted to GMOD and the output from GMOD was used by SYSMOD (*Figure3.*) SYSMOD was used to determine the groundwater pumping and the artificial recharge over the historical period. GMOD calculated the groundwater elevations based on the pumping and the artificial recharge reported by SYSMOD that occurs in the basin and determined the basin's storage capacity.

Figure 3:SYSMOD\GMOD Integration



The groundwater elevations calculated by GMOD were compared to the established criteria of staying below the historical highs and above the elevation where subsidence could begin. The groundwater basin capacity in SYSMOD was adjusted if this criterion was violated. For the next iteration, another set of pumping and recharge quantities was calculated by SYSMOD for input to GMOD and groundwater elevations were again compared to the criteria. This iterative process continued until the groundwater elevations calculated by GMOD stayed within the criteria and the change in storage calculated by SYSMOD and GMOD showed substantial agreement.

For planning purpose, SYSMOD has subdivided the basin into West, Central and East subbasins and additionally calculates the water balance for each of these subbasins (*Figure 2.*) These sub-regions were also created in GMOD and the water budget was separated into these sub-regions and also to the confined and forebay zone to coincide with SYSMOD's subbasins. The inter-basin exchange occurring among these three subbasins during the simulation was calculated by GMOD and was passed to SYSMOD.

Assumptions

In this analysis, the groundwater extractions were limited to the existing well locations in each service area with the same spatial distribution as of 1994 where the highest groundwater pumping occurred since the Santa Teresa Water Treatment Plant came on-line. The groundwater pumping from each service area was limited to its historical maximum when possible.
The operational assumptions used in the system analysis are:

- Water demand = 500K ac-ft.
- IWRP recommendations for this demand level.
- State Water Project (SWP) entitlement = 100,000 ac-ft/yr.
- Central Valley Project (CVP) entitlement = 152,500 ac-ft/yr.
- Hetch-Hetchy deliveries are based on SWP deliveries in the same manner that they were modeled during the IWRP process.
- The CVP M&I preference policy maintains a 75 percent floor for minimum delivery based on the M&I portion of the entitlement.
- Health and safety criteria was used in 1977(That is no CVP M&I floor was used.)
- The reduction in deliveries from the SWP that was determined by the DWR and complied with the 1994 December Bay-Delta Accord.
- Banking 350,000 ac-ft of water in the Semitropic Storage District was incorporated in this analysis. This analysis also included additional conservation (11,000 ac-ft above BMP), 13,800 ac-ft/yr. recycled water, and 50,000 ac-ft/yr. of additional water transfers.

Problems Encountered and Resolutions

During this investigation some problems were encountered that required changes to be made in the analysis. The following were the most significant problems encountered and the action taken to resolve the problems.

- Some of the cells in GMOD became "Dry" as a result of the simulation. When this occurs, the cell becomes inactive and acts as barrier to groundwater flows both into and out of the cell (pumping and recharge are stopped after the cell goes dry). The pumping at these cells were decreased and additional pumping was added in adjacent and/or nearby cells to reflect the total pumpage in the basin. This technically smoothed out the pumping and prevented the heavily pumped "problem" cells from going dry.

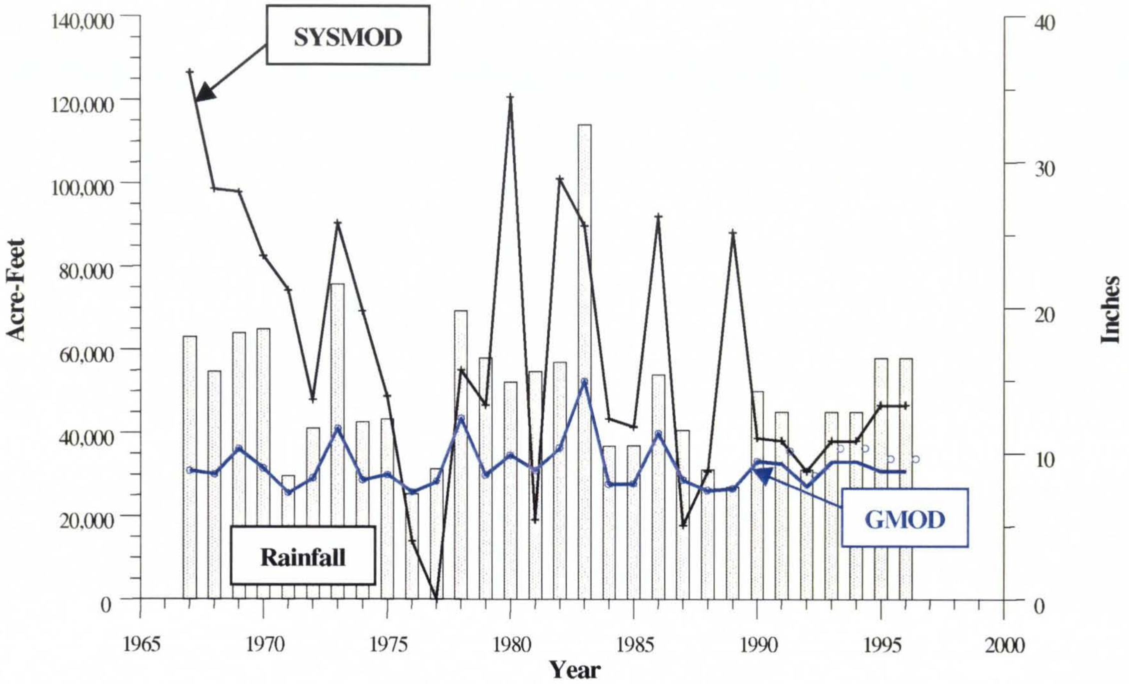
- One water service area was being served by the retailer's wellfield outside of the groundwater basin where the service area was located. Hence, the water service area in SYSMOD did not reflect the actual location of pumping in the basin. This water service area was changed to a different subbasin in SYSMOD to reflect the actual location of pumping.

- One of the major components of the water budget is the natural recharge that occurs in the basin. This is the recharge that occurs in the basin regardless of District activities. Rainfall is a component of this recharge and is shown on the right axes of *Figure 4* ranging from a low of 7 inches in 1976 to a high of 32 inches in 1983. Historically, this natural recharge was back calculated from other terms in the water budget; pumping, recharge and change in storage. This was the method used in SYSMOD and it ranged from a high of about 127,000 ac-ft to 0 ac-ft. However, GMOD calculated the natural recharge in the basin by directly estimating it from components that contribute to this recharge such as rainfall, return flows, etc. These two estimates for natural recharge shown in *Figure 4* were not identical which lead to a discrepancy and difficulty for the two models to calculate the same basin response.

  The GMOD estimate was further refined to only account for the natural recharge that infiltrates into the unconfined aquifer of the basin. The long term average annual natural recharge from SYSMOD was about 59,000 ac-ft in comparison to about 32,000 ac-ft from GMOD's direct method. This average decreased to a value of 41,000 ac-ft for the critical dry period in SYSMOD and decreased to 30,000 ac-ft for the same period using GMOD calculations.

  After several iterative simulations this was resolved by using the direct methodology for calculating this natural recharge for both models in this investigation. These two methods will be analyzed further in the future.

Figure 4:SYSMOD vs. GMOD Natural Recharge



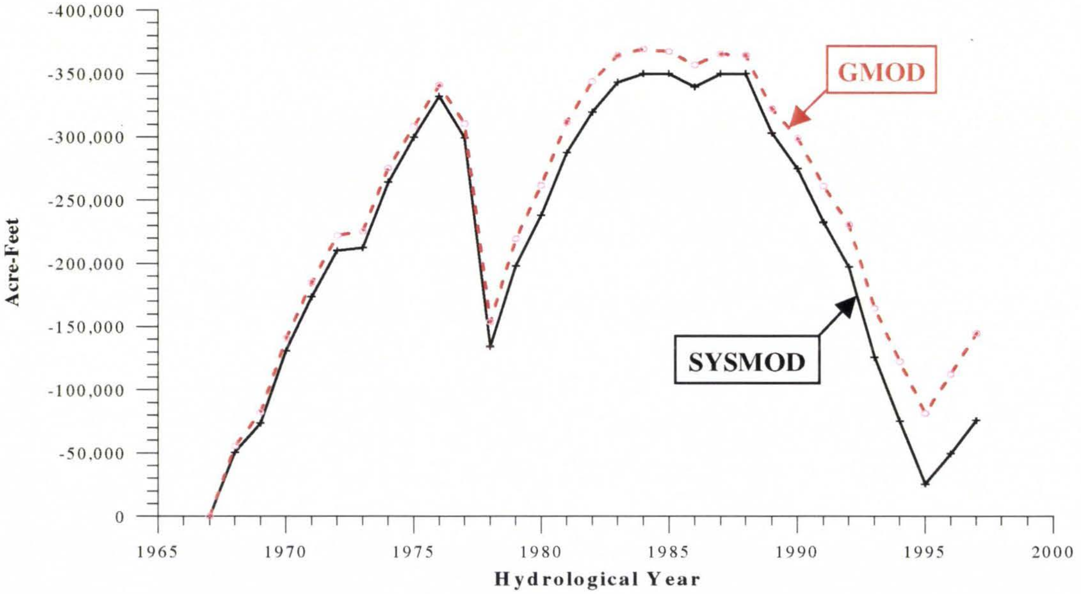
MODEL RESULTS

This section presents the results of the modeling effort to determine the groundwater storage that is available to meet the 2020 water supply demands using the IWRP's maximum action strategy.

The groundwater basin acts as a source of supply and transmission of this supply to areas where water is pumped from the basin. The basin is also used as a storage facility. The water stored in the basin provides the hydraulic heads needed to maintain the groundwater elevations above the subsidence thresholds. SYSMOD analyzed the water supply conditions and assured that the demands are met without jeopardizing the groundwater basin.

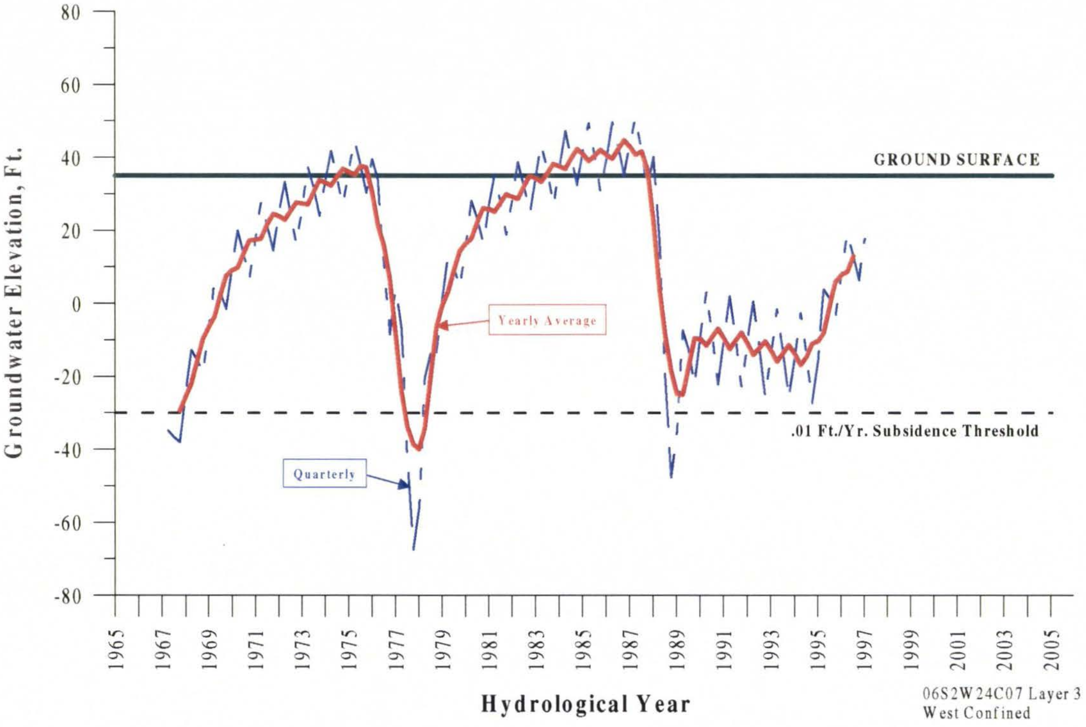
After many iterative simulations between SYSMOD and GMOD, a solution was reached between these two models on the operation of the groundwater basin. This solution is based on the current policies and programs that guide the operation of the water utility and the recommendations developed during the IWRP process.

Figure 5:Simulated Groundwater Storage for Santa Clara Valley Basin



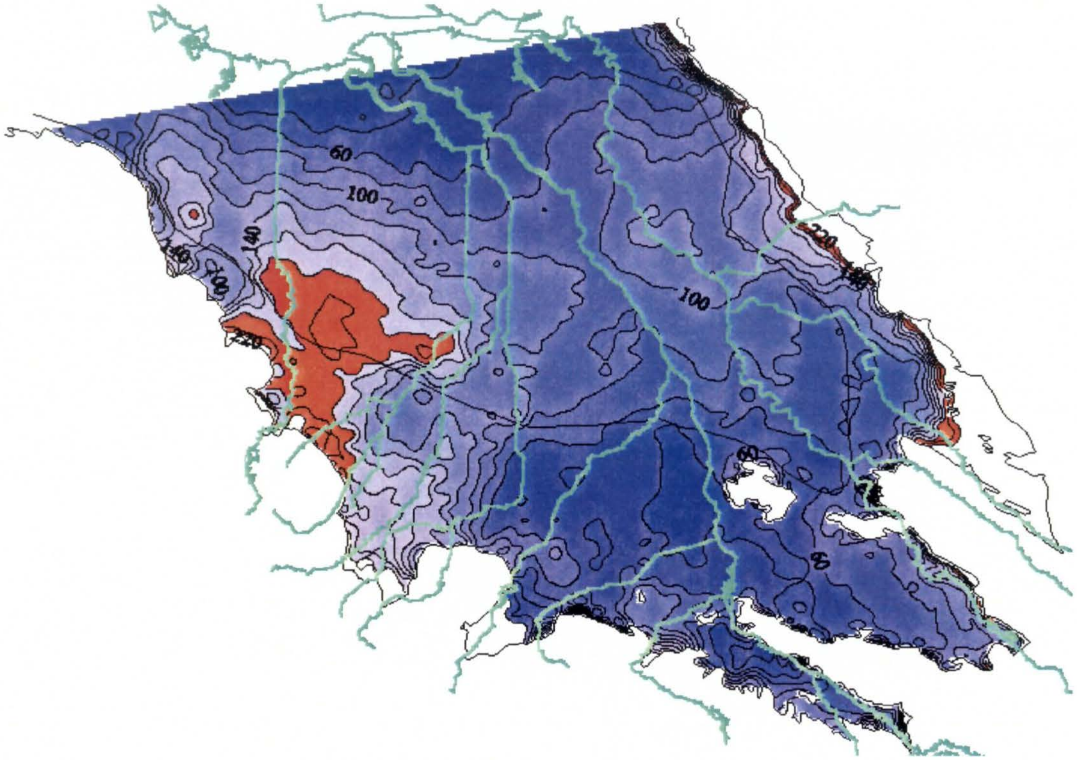
The basin was operated with historical hydrology starting in 1967 with the initial groundwater basin levels set to zero operational storage (a conservative assumption) which represented the subsidence threshold, see *Figure 5*. Through a series of above average rainfall, the basin storage builds up to the level that is sufficient to withstand the water supply shortages of the 1976-1977 drought. Although, the groundwater storage in 1977 is 130,000 ac-ft some of the wells approach the subsidence thresholds and in some cases surpass the thresholds for a short period of time during the 1976-1977 drought, see *Figure 6*. Although groundwater elevations are computed quarterly, the yearly average is used to determine if subsidence will recommence. The maximum drop in groundwater storage for a single year occurred during this period where the basin storage dropped by more than 150,000 ac-ft. Most of this storage change occurred in the central subbasin that increased pumping over the two hydrological years of 1976 and 1977 because of reduced deliveries from Santa Teresa Water Treatment plant to this subbasin.

Figure 6:Simulated Groundwater Elevation



The imported water supplies for the 1976-77 drought conditions are drastically reduced compared to a normal year. The combined CVP and SBA deliveries are reduced to 46,000 ac-ft and Hetch-Hetchy deliveries are reduced to 42,000 ac-ft. The deliveries from the bank because of take restrictions only account for 29,000 ac-ft. As a result the water treatment plants can not be fully supplied and the pumping in the basin exceeded 215,000 ac-ft, more than a 200% increase of annual pumping. During the same period because of the lack of supplies, recharge in the basin decreases by more than 600% to a low of 18,000 ac-ft. The combination of increase in pumping and the decrease in recharge causes some of the wells to surpass their subsidence thresholds. The groundwater elevations in the west subbasin are impacted the most and the lowest groundwater elevation occurred in 1977 as shown in *Figure 7*.

Figure 7:Simulated Low Groundwater Levels (1977) - Depth to Water

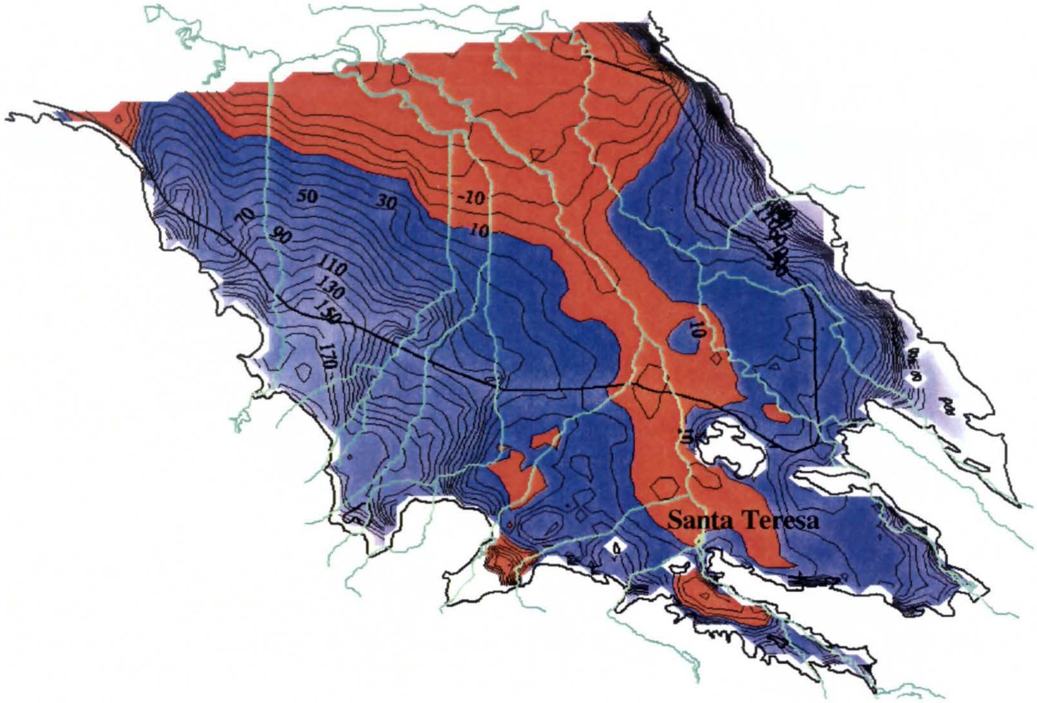


The basin storage recovers to its maximum level of 350,000 ac-ft within six years after the hydrological condition of the 1976-77 historical drought. This operational storage is maintained for several years before the critical dry period (1987-1996) is encountered. During the high groundwater storage levels, some areas of the basin - especially the Santa Teresa region of central subbasin - experience high groundwater elevations as shown in *Figure 8*. During the critical dry period all of the wells were above the subsidence threshold.

These high groundwater levels extend beyond the confined zone. As the water levels in the forebay rise above the bottom of the creeks and rivers, the water will be drained into these creeks and rivers and discharged from the basin. However, these physical drains are not modeled in the current GMOD and therefore the resulting groundwater elevations are higher than what is expected to actually occur in the basin.

The natural recharge accounted for 32,000 ac-ft of annual water supply during the 1967-1996 hydrology. The years 1977 and 1983 represent the minimum and the maximum local and imported water supply conditions for this analysis.

Figure 8: Simulated High Groundwater Levels (1983) - Depth to Water



During the 30-year period of analysis an average of 90,000 ac-ft/yr was artificially recharged in the basin with a maximum of 125,000 ac-ft being recharged in 1967 and 18,000 ac-ft in 1977. Current operational practices, facilities and recharge rates were used in this analysis. The 1977 recharge of 18,000 ac-ft occurred when there was minimal local water supply and no imported water available for artificial recharge.

The average pumping prior to the 1976-1977 drought was 108,000 ac-ft. This pumping increased to 215,000 ac-ft in 1977. More than 100,000 ac-ft of this pumping is in the central subbasin because of a lack of imported water. The basin pumping was reduced to an average of 110,000 ac-ft for the years prior to the critical dry period. However, because of the water supply shortages during the critical dry period the groundwater pumping was again increased to an average of 126,000 ac-ft to meet the demands for this critical dry period.

Therefore a severe drought requires 18,000 ac-ft /yr of additional groundwater pumping. This represents an increase of about 17% of average annual groundwater pumping.

KEY FINDINGS

From this analysis the following key findings were determined:

- The operational Storage capacity is estimated to be 350,000 ac-ft.
- The rate of groundwater withdrawal has an impact on the operation of the basin. Although there is no need to alter the current operation of the basin, the maximum pumping during any one-year should not exceed 200,000 ac-ft to prevent subsidence from occurring.
- The water utility's facilities in the west subbasin have a great impact on the operation of the basin. Hence, the deliveries to and operation of the Rinconada Water Treatment Plant has to be prioritized to maintain the west subbasin when water to the treatment plants need to be curtailed.

FUTURE STUDIES

This section describes the future studies that need to be completed to further refine and improve the understanding of the groundwater basin.

IWRP

The IWRP action plans were based on operational Storage of 250,000 ac-ft along with other assumption on imported supplies. The imported supply assumptions have changed as well as the operational storage of the groundwater basin. These could have some impact on the IWRP action plans and should be reviewed. Although, the full operational storage of the basin is estimated to be 350,000 ac-ft, a detail analysis of risk of utilizing this entire storage and stressing the basin to its limit during the droughts should be investigated to determine if this is appropriate.

Subsidence

Drawdown Curves

The subsidence thresholds that were developed for the PRESS index wells were based on the assumptions that the basin will be drawn down for two years and then maintained at that level for two years before it would rebound to its original levels. The simulation performed for this project indicated that this draw down is not necessarily how the basin will be operated. The drawdown should reflect the expected operation of the groundwater basin and from this, a new subsidence threshold should be determined.

Inter-bed Storage

The subsidence thresholds were developed using the PRESS one-dimensional model at 10 discrete locations. A new module for MODFLOW, the Aquifer-System Compaction will allow for analyzing the subsidence throughout the entire area of the basin. This module models the clay lenses in their actual forms and will allow for the model to account for the storage lost due to subsidence. This module will allow the comparison of subsidence levels at seasonal low and high groundwater elevations when subsidence occurs or basin rebounds rather than the average annual values used in PRESS. This method needs to be compared with the method now in use and the better methodology needs to be carried forward.

Subsidence Rate/Thresholds

For this analysis a subsidence rate of .01 ft/yr was used. However, a subsidence rate greater than .01 ft per year may provide more operating storage/capacity for the groundwater basin. Currently, the District is working with the USGS to improve its monitoring of subsidence in the basin. Preliminary analysis of this work indicates that the basin experiences .08 ft of elastic subsidence in a season. The elastic subsidence is recoverable and would not impose limitations on the operational storage of the basin. The in-elastic subsidence rate will have an impact on the operational storage and should be differentiated from the elastic portion. The elastic range needs to be determined and then incorporated into the analysis.

Geo-Hydrology

The preliminary analysis of satellite images indicates that the Silver Creek fault may have an impact on the groundwater flow system. The conceptual model used for developing the groundwater model did not account for any impact from this fault or any other faults in the basin. This investigation should continue and appropriate changes to GMOD should be made to account for these fault barriers and their impact on the groundwater flow and the storage if found to be correct.

Natural Recharge

An important source of supply is the natural recharge occurring in the basin. There are two methods used to estimate this source of supply. Natural recharge has several components of which one is rainfall. The estimate for the recharge from rainfall does not consider soil saturation. Hence, the percolation from the rainfall continues to increase and does not cap at high rainfall levels. This assumption will result in erroneous natural recharge for years with extremely high rainfalls. Historically, a water balance method has been used to compute the natural recharge, which is different from the method used by in GMOD. The two different methods need to be resolved.

GMOD Refinement

The groundwater model was developed based on our understanding of the hydrogeology of Santa Clara Valley Basin. The MODFLOW numerical code that was used for GMOD is being improved with modules being developed to model the hydrogeological features that were not modeled in the past. Data collected since the calibration of the model will help in refining the basin parameters and utilizing other modeling tools to mimic the complexity of the groundwater system and its interaction with the surface system. The addition of modules such as river or drain packages to directly represent creeks and rivers will enhance the model and improve the modeling of potential high groundwater conditions.

Basin Management

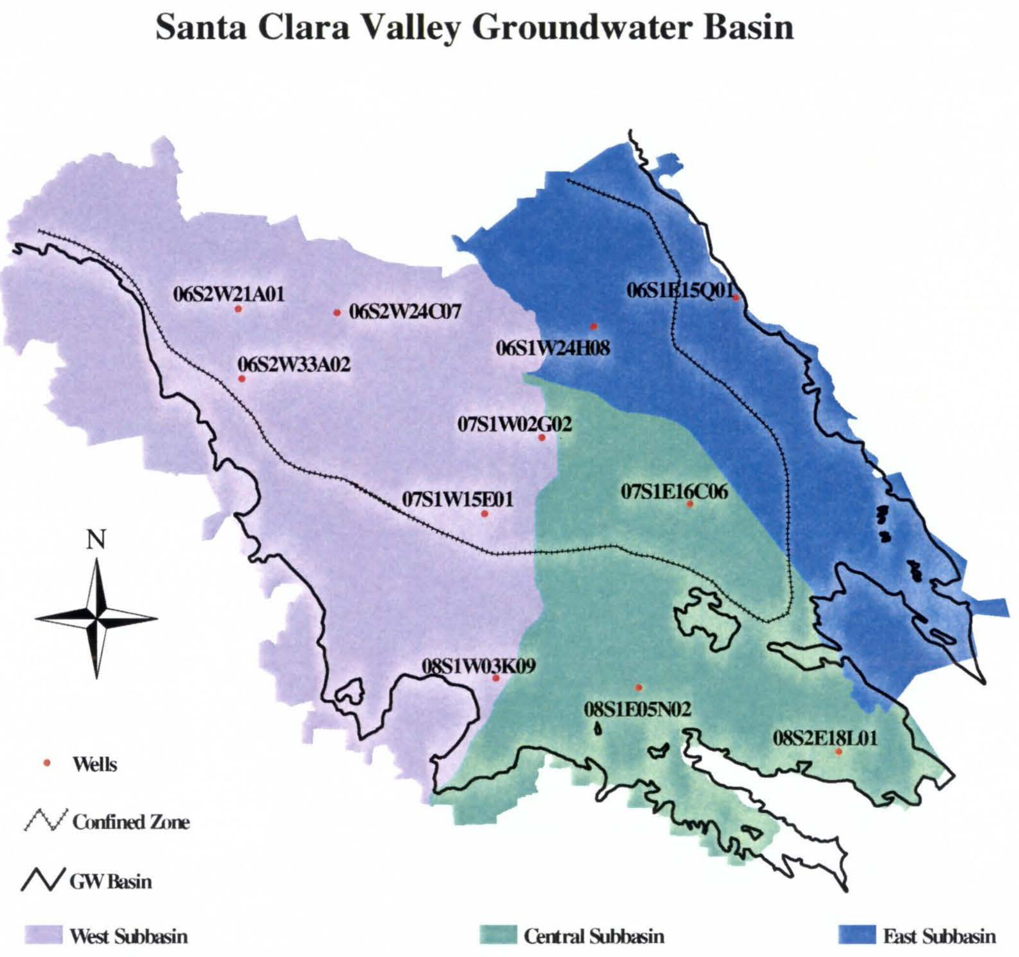
The operation of the groundwater basin has a great influence on the outcome of the operational storage. This project was based on the existing operation of the basin and adhered to current practices. Currently, the Groundwater Management Plan is documenting the programs and practices that are operated in the basin. This document needs to be evaluated and alternative operational practices need to be identified. After this, an optimal operational objective will be developed and GMOD will be used to test this objective function.

APPENDIX A

Appendix A displays the hydrographs for a selected set of wells in the basin. These hydrographs are grouped by the subbasin that they represent and within each subbasin they are also divided into the confined or the forebay part of the subbasin. The locations of these wells are shown in *Figure 9*.

Although groundwater elevations are computed quarterly, the yearly average levels are compared to the subsidence thresholds because these thresholds were established using the yearly average data.

Figure 9: Location of Wells



Central Subbasin

The wells in the confined zone of this subbasin went below the subsidence thresholds on a quarterly time step but the yearly average was above these thresholds. This subbasin is not expected to experience subsidence for the hydrology investigated.

The well 08S1E05N02 in the forebay zone *(Figure 12)* of this subbasin reached the ground surface about 20 feet higher than its historical maximum. This could indicate a problem. However, GMOD does not account for the natural drainage out of the basin to creeks and rivers and when GMOD is updated to account for this drainage these high groundwater conditions may not show in the hydrographs.

Figure 10: Confined Zone

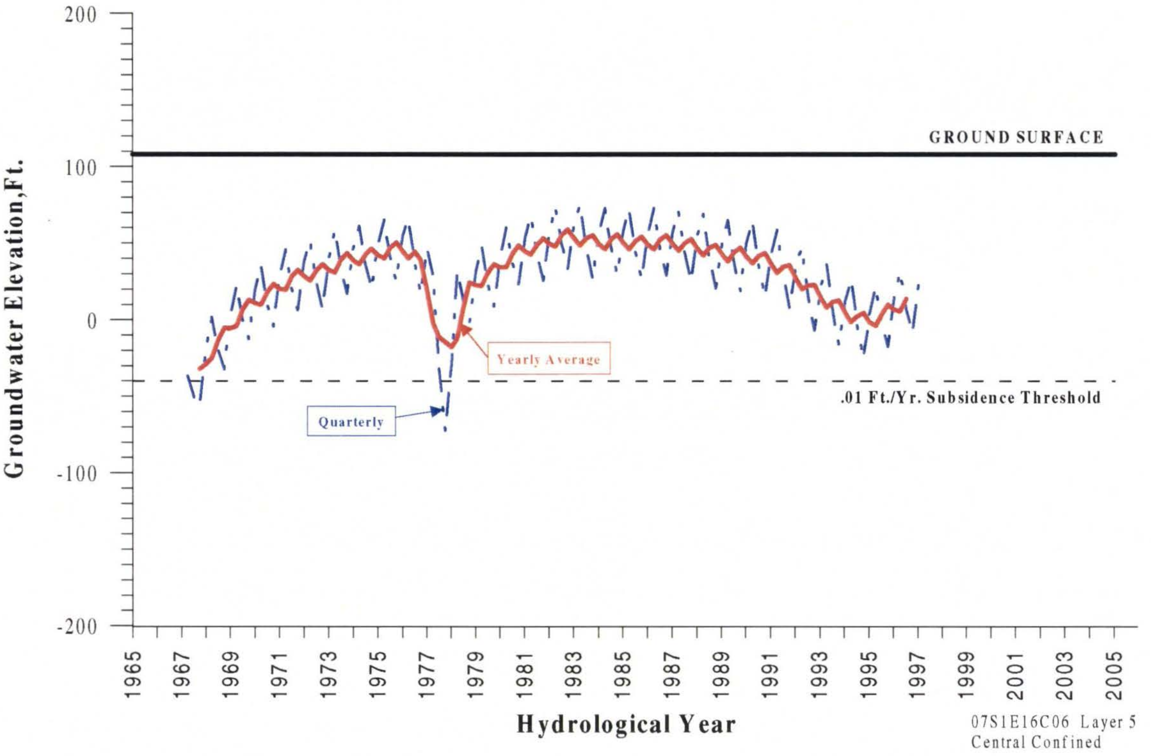


Figure 11: Forebay Zone

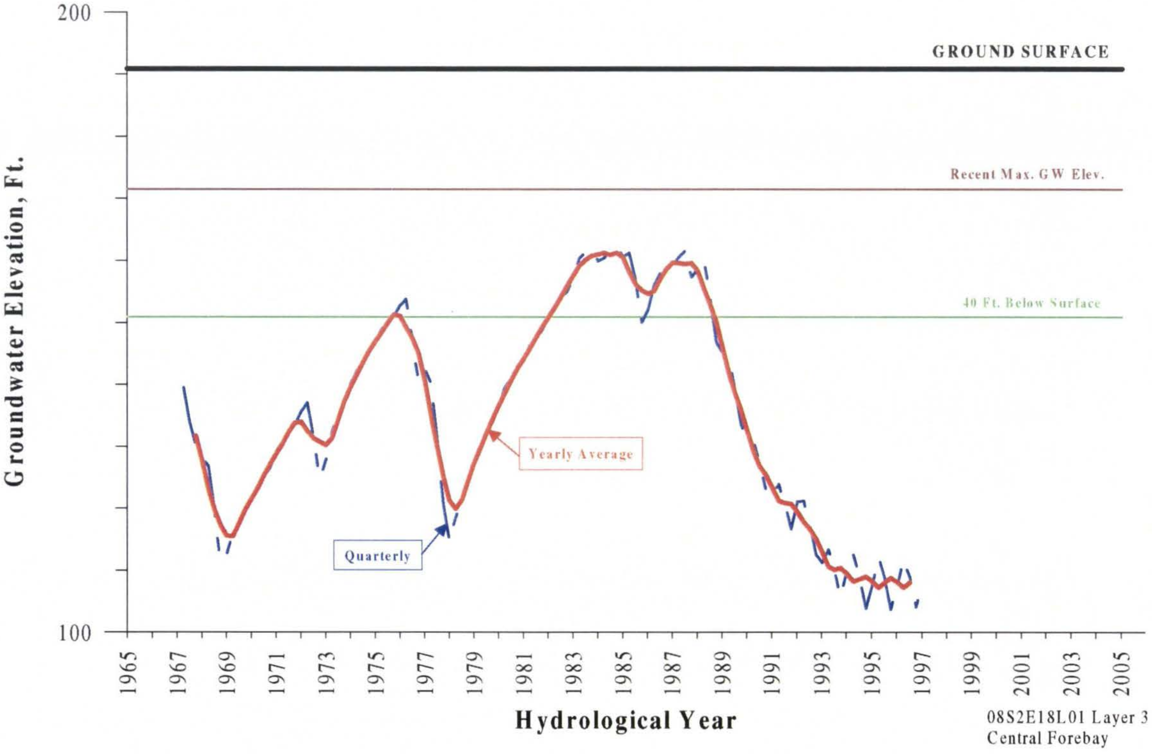
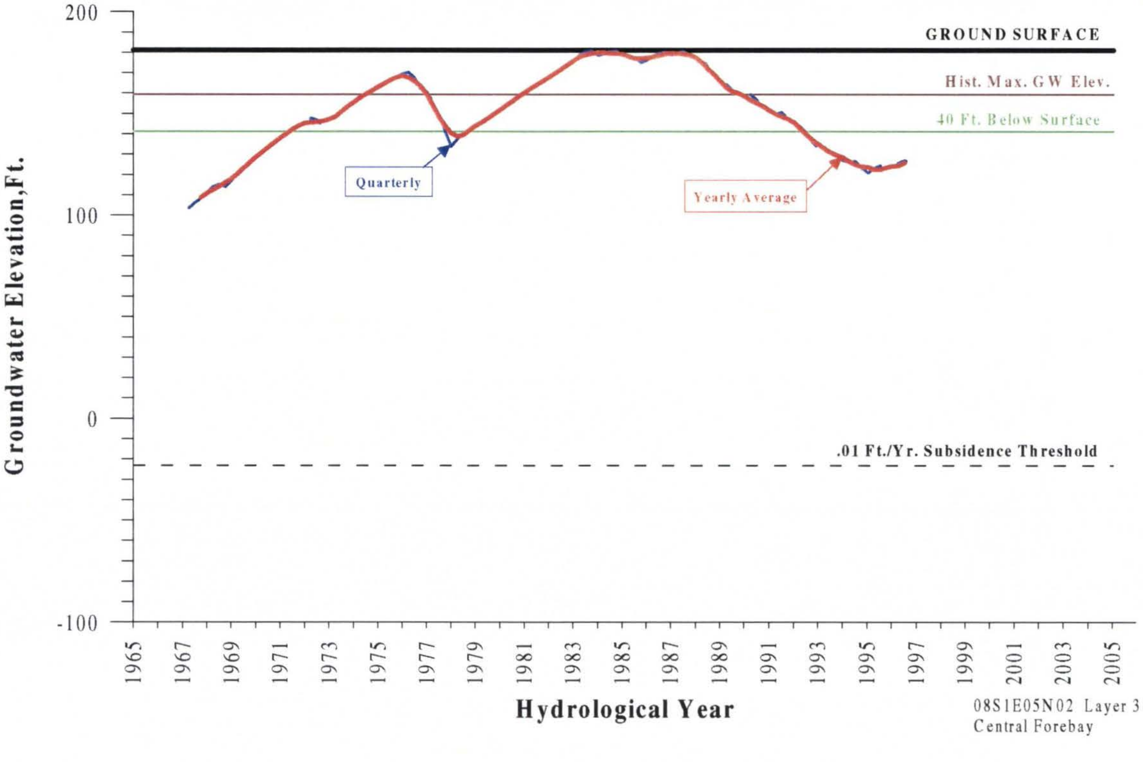


Figure 12: Forebay Zone



East Subbasin

The drought of 1977 causes the wells in this subbasin to exceed their subsidence thresholds on quarterly time steps but also for the yearly average. The forebay well does not indicate any problems during the drought or display any high groundwater level conditions during wet years.

Figure 13: Confined Zone

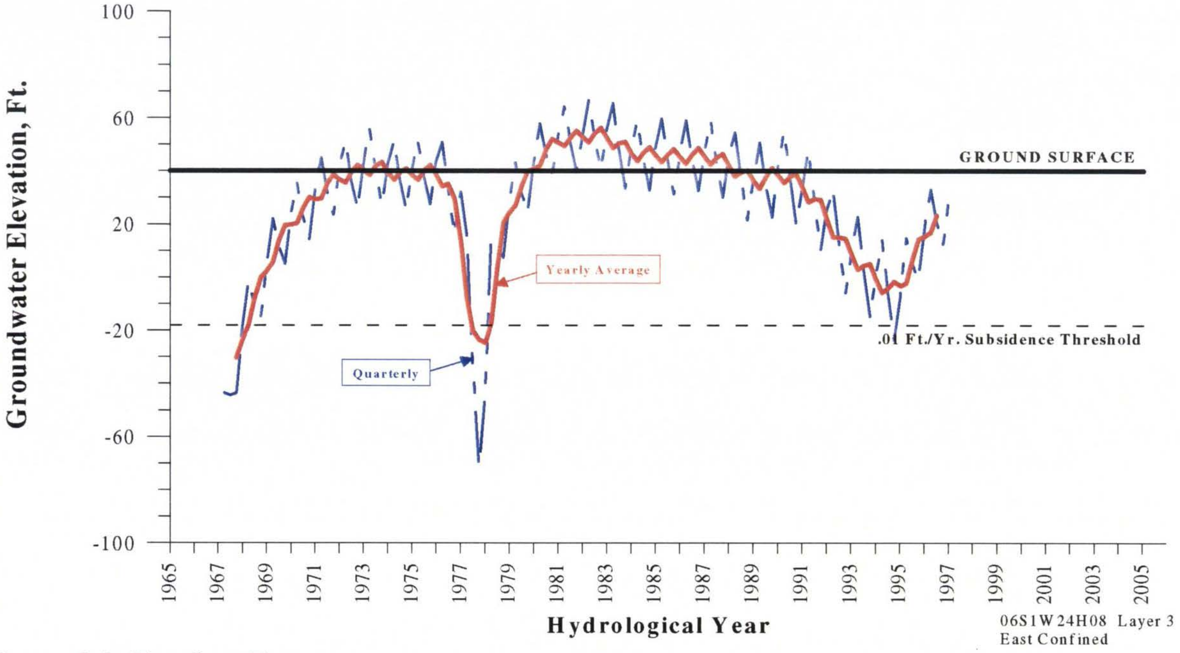
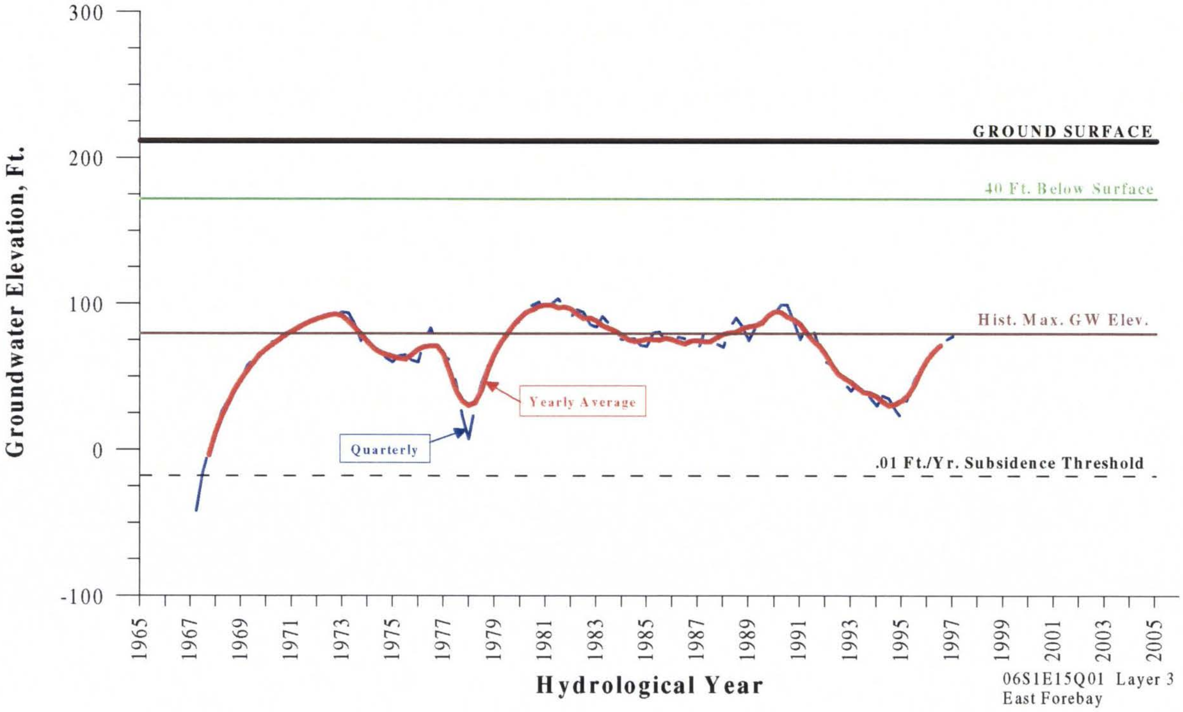


Figure 14: Forebay Zone



West Subbasin

The delivery of treated water from Rinconada Water Treatment Plant to this subbasin was prioritized to assure that the wells in this subbasin would not go below their subsidence thresholds. Although some of the quarterly water levels for the wells in the confined zone exceed their subsidence thresholds, the majority of the annual water levels did not go below the thresholds. The exceptions were the wells 06S2W24C07 in the confined zone when the yearly average exceeded its subsidence threshold in 1977 and 08S1W03K09 in the forebay zone when the yearly average exceeded its subsidence threshold in 1994.

Figure 15: Confined Zone

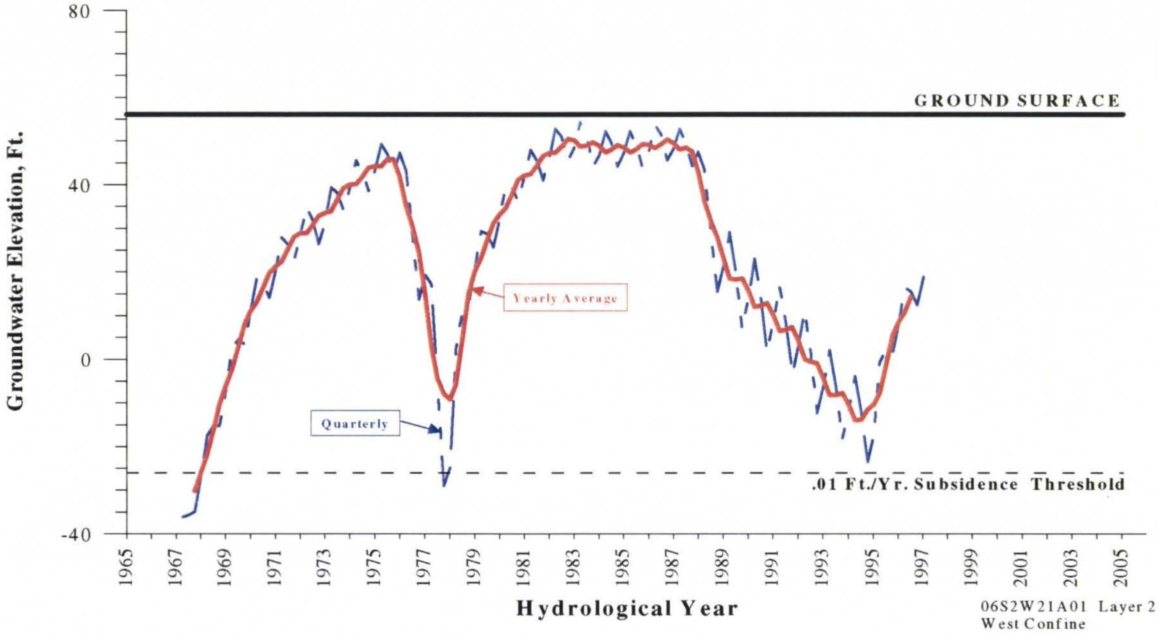


Figure 16: Confined Zone

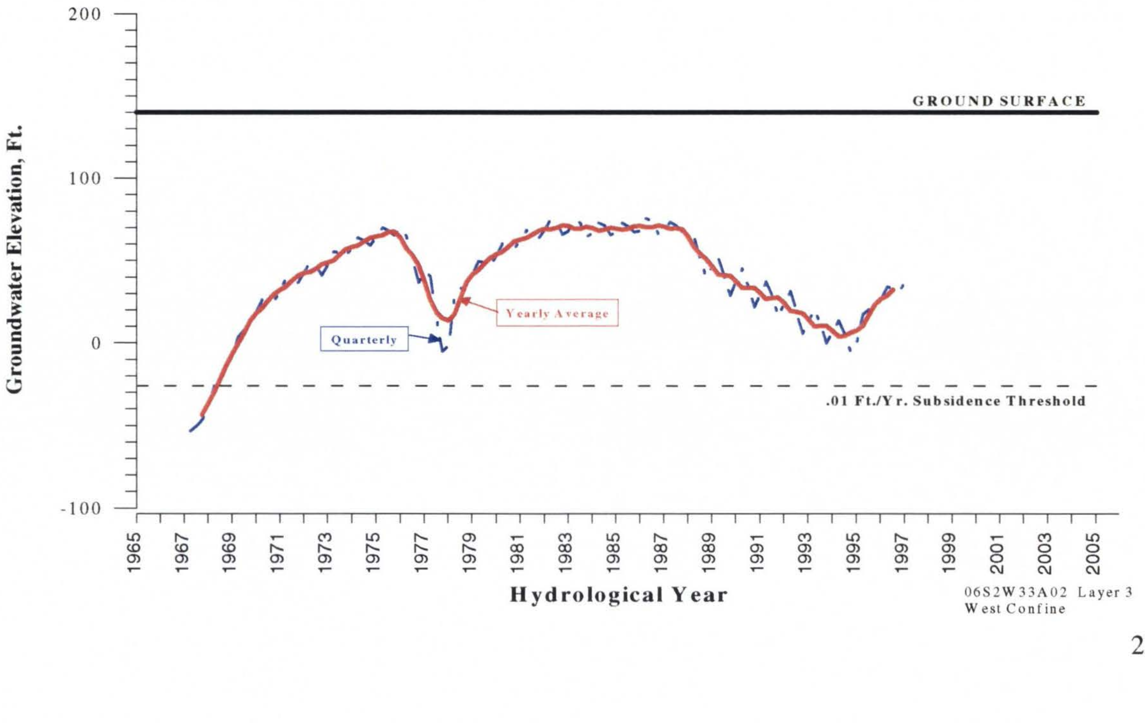


Figure 17: Confined Zone

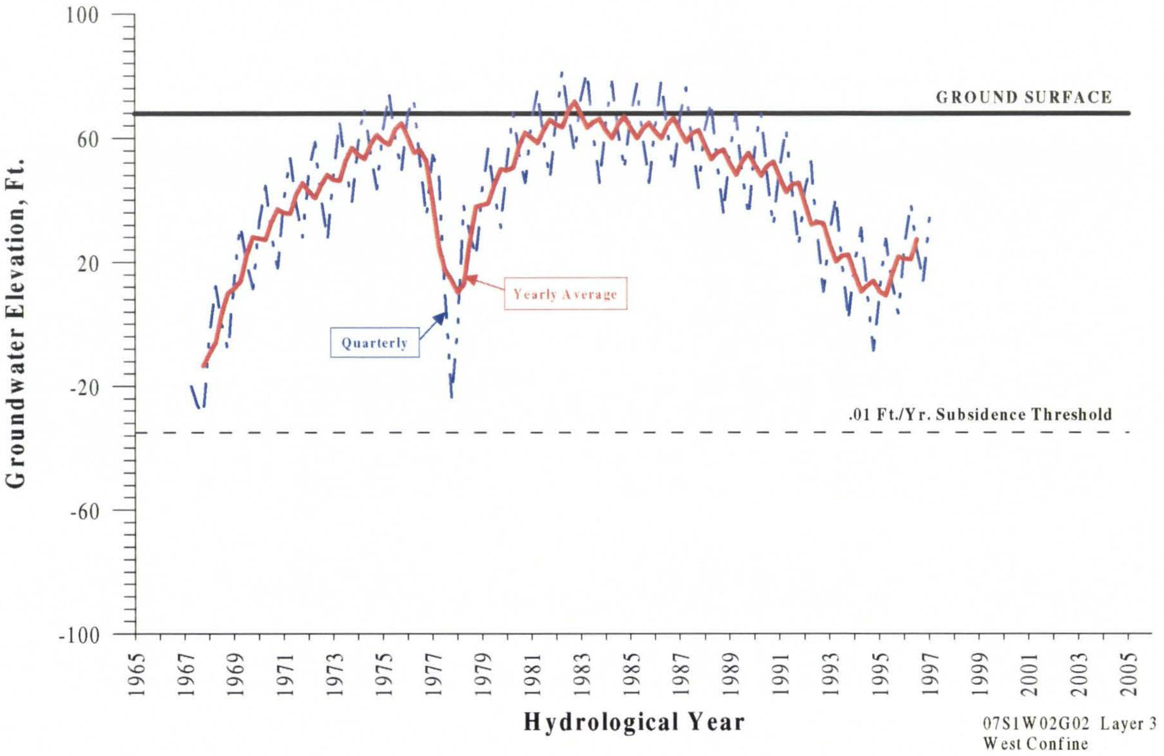


Figure 18: Confined Zone

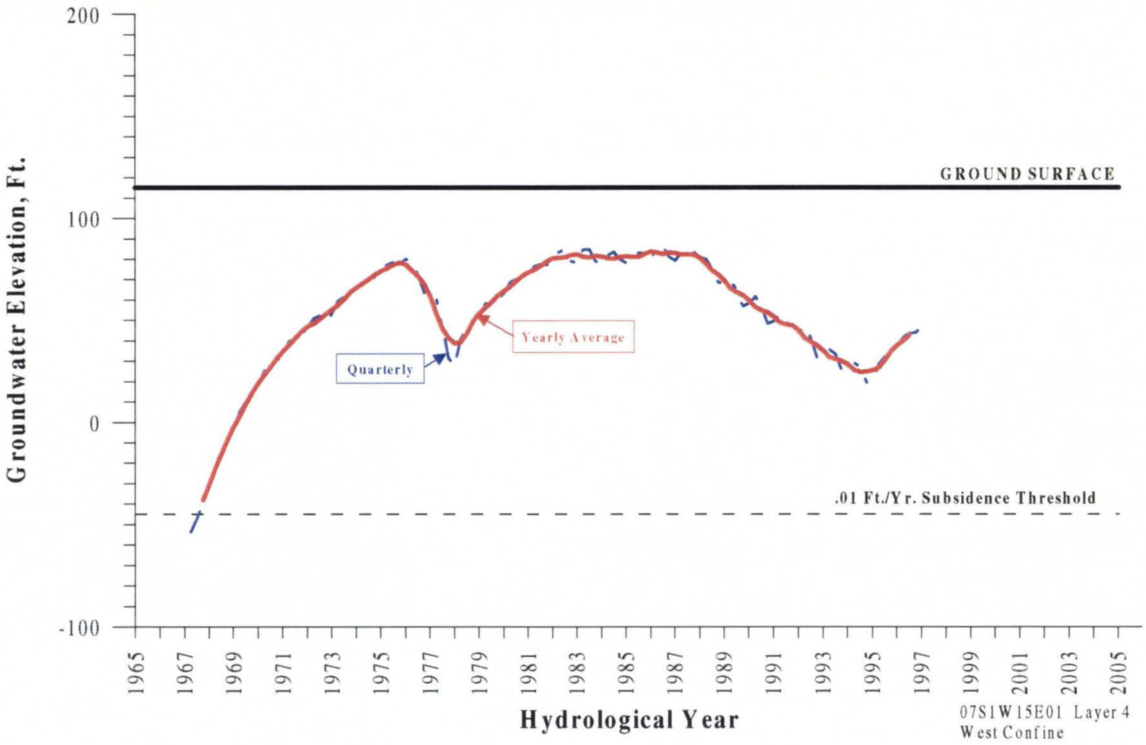


Figure 19: Confined Zone

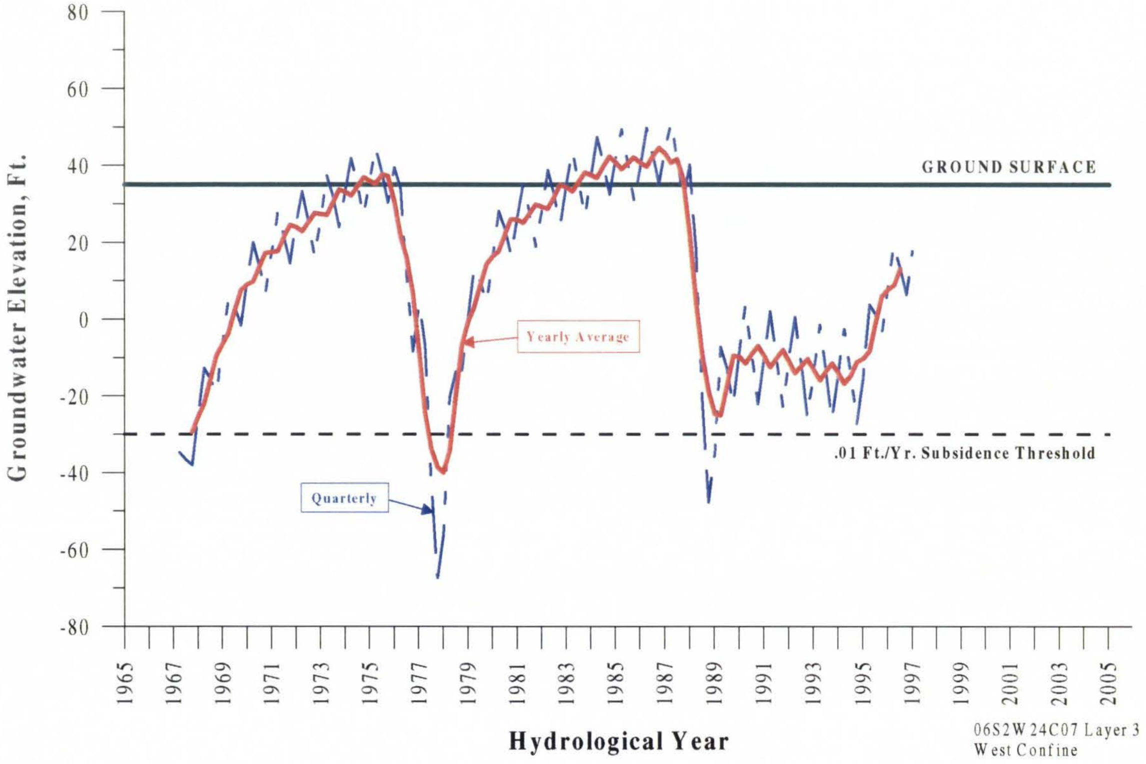
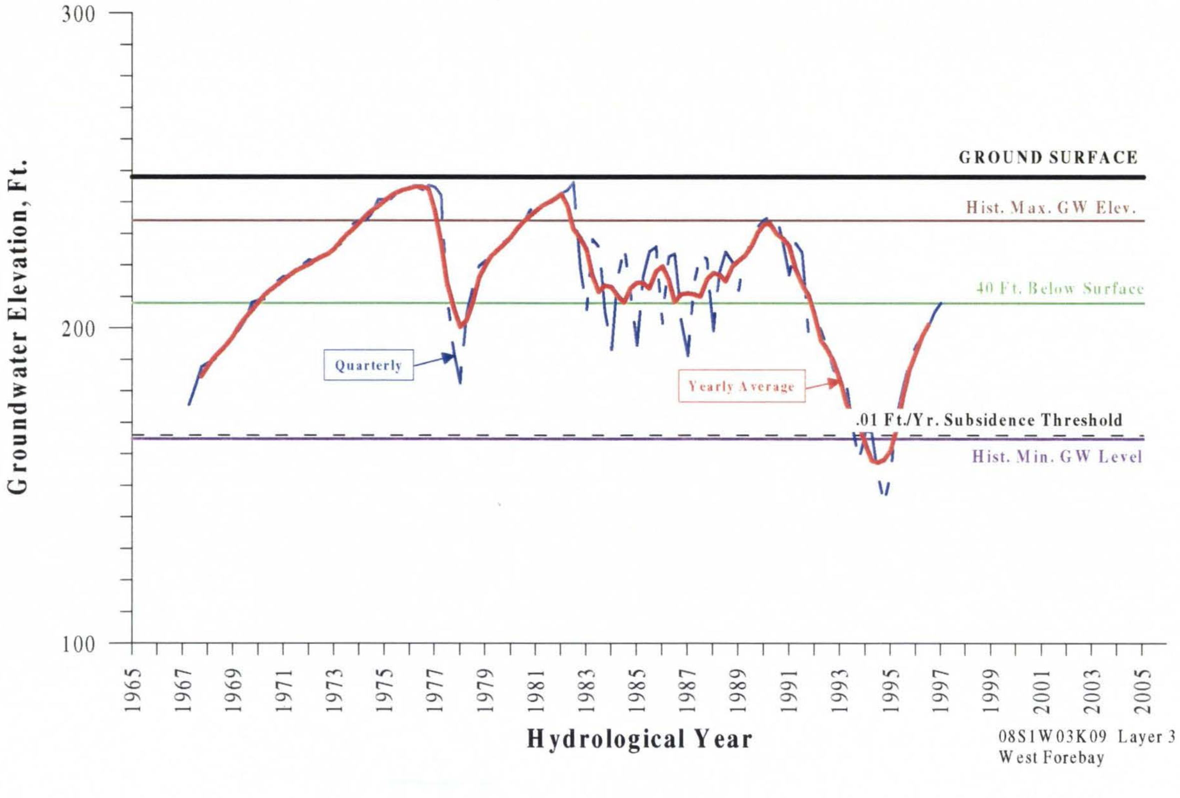


Figure 20: Forebay Zone

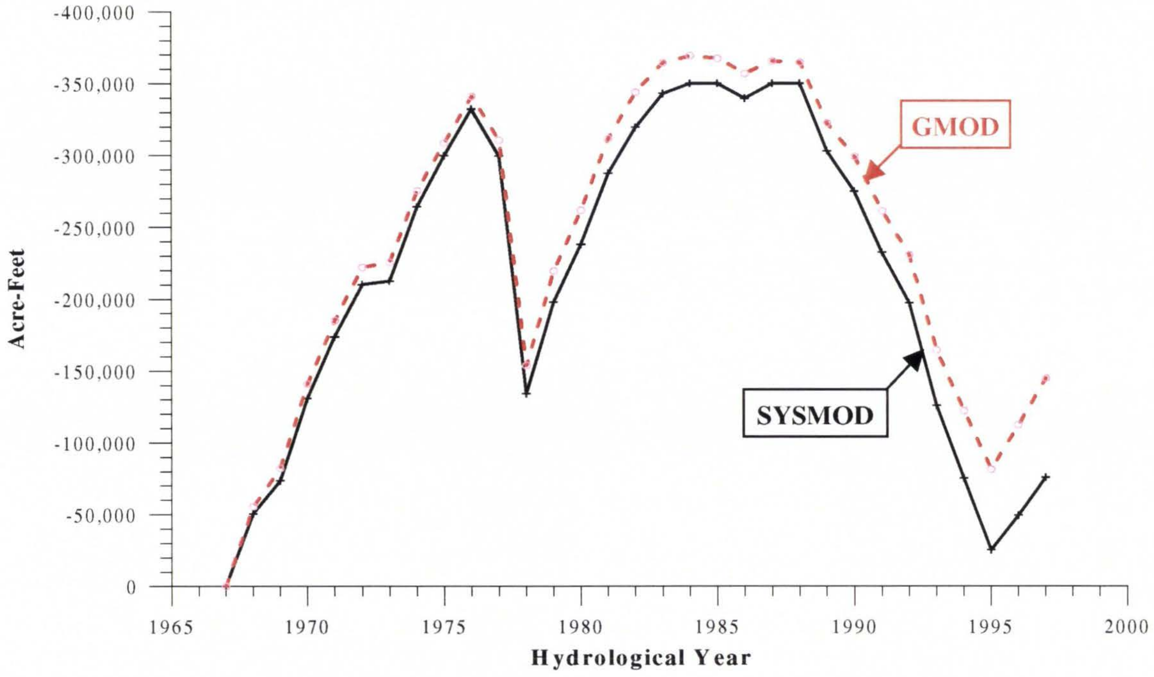


APPENDIX B

Appendix B displays the water budget – cumulative storage, pumping, artificial recharge and the natural recharge for the entire basin.

The cumulative groundwater storage is shown in *Figure 21*, which also shows the comparison between the two models. The horizontal axis shows the years with equivalent hydrology. The basin reaches its operational maximum in a year with 1983 hydrology.

Figure 21: Cumulative Groundwater Storage for Santa Clara Valley Basin



The annual groundwater pumping in the basin is shown in *Figure 23*. In a year with 1977 hydrology, the basin would be pumped at its maximum of 218,000 ac-ft because of surface water supply shortages for treatment plants to meet their demands this shortfall is made-up from the groundwater basin.

The 1977 pumping distribution for areas with annual pumping of more than 2,000 ac-ft is shown in *Figure 22*. The confined zone pumping accounts for the majority of pumping in the basin for this year as well as most years.

Figure 22: 1977 Groundwater Pumping Distribution

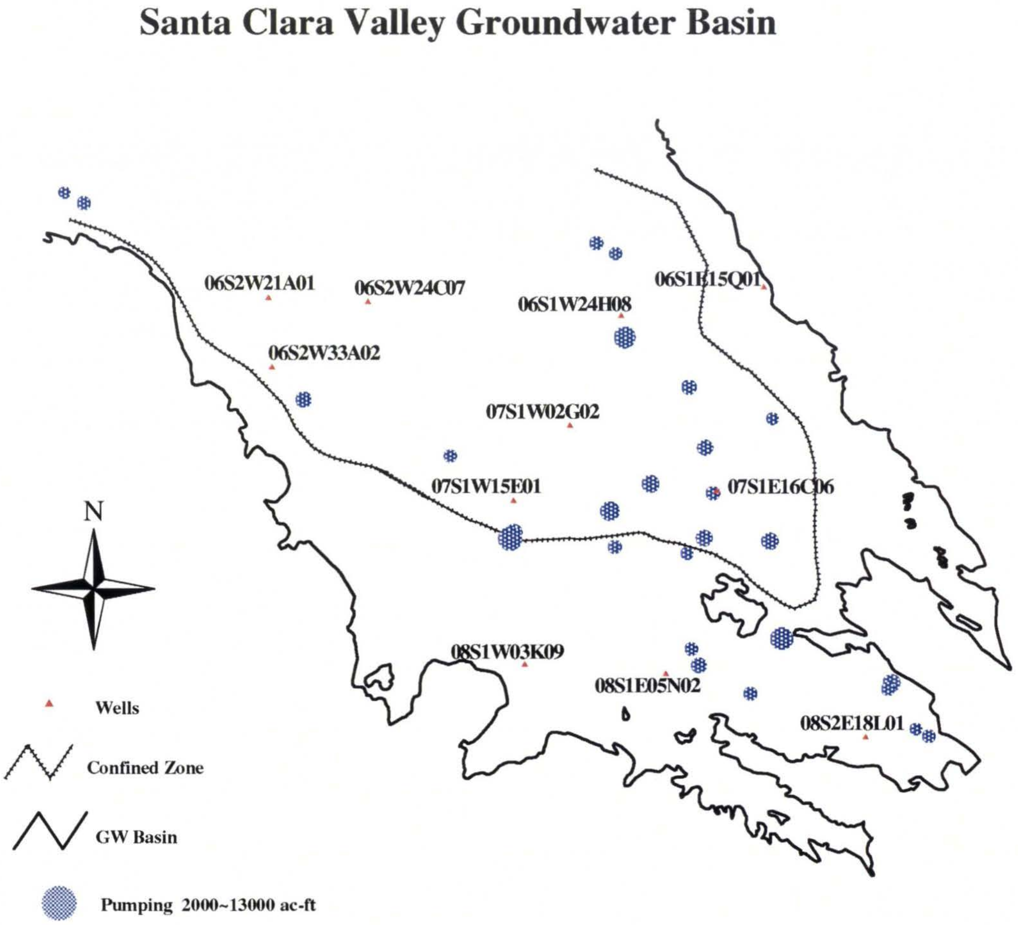
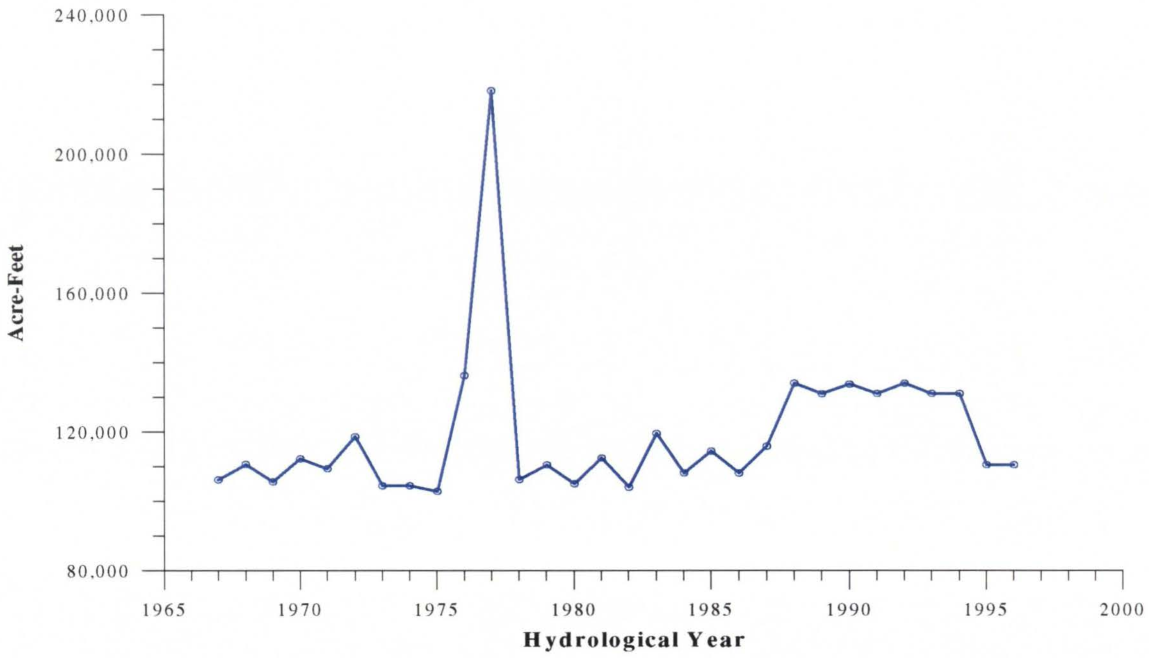


Figure 23: Basin Groundwater Pumping



The groundwater is recharged naturally from the rainfall, return flows, surface and subsurface flows from mountains as well as artificial recharge from District operations. The natural recharge and the artificial estimates are shown in *Figures 24-25*. The artificial recharge in the basin is reduced during the dry periods, as there is not enough available supplies to meet treatment plants as well as the artificial recharge requirements.

Figure 24: Basin Natural Recharge

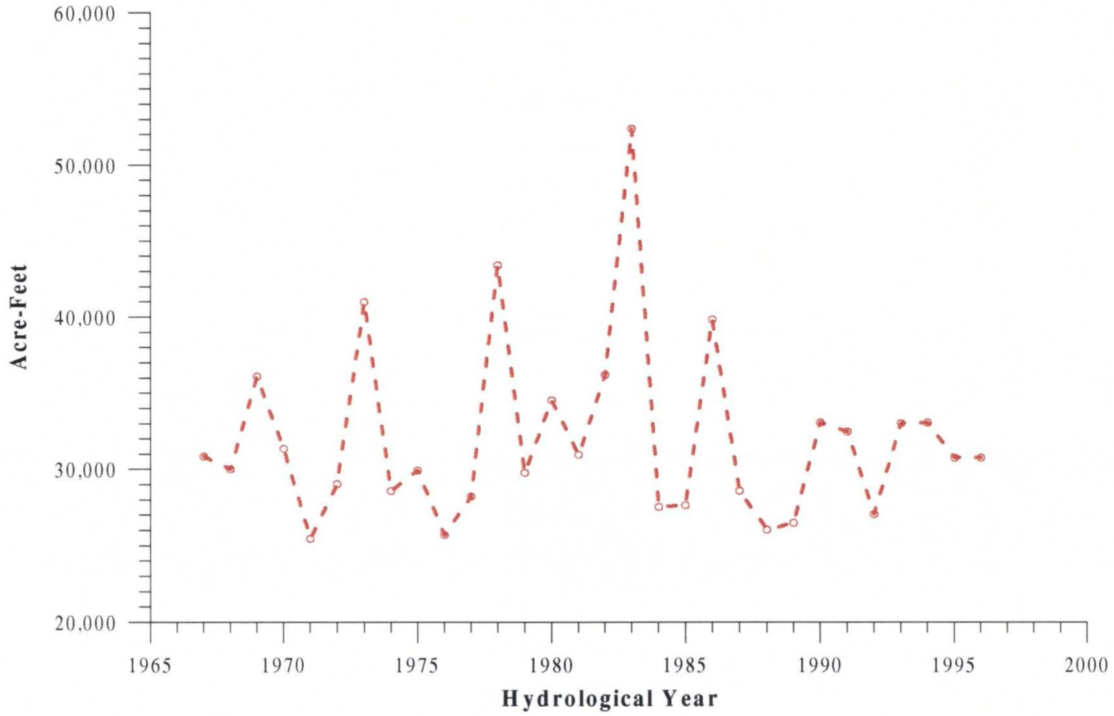
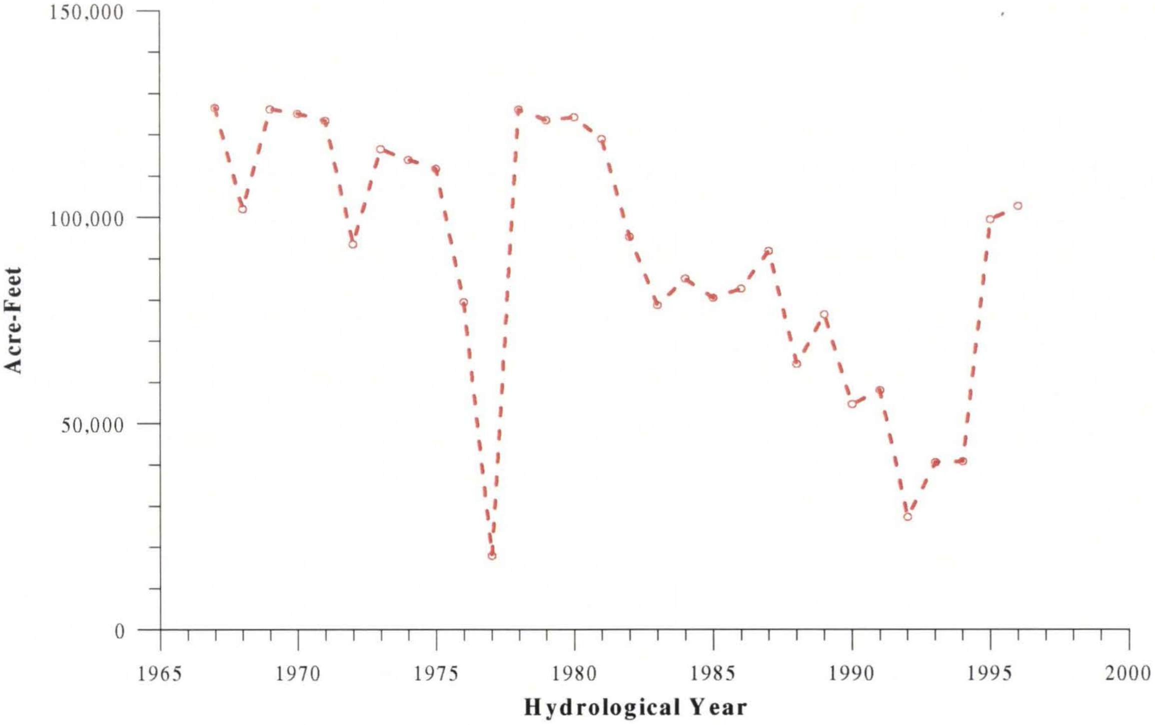


Figure 25: Basin Artificial Recharge



APPENDIX C

Appendix C displays the water budgets – inter-basin exchange, pumping, recharge and storage - for each subbasin.

GMOD calculates the subbasin exchange that occurs and this data is transferred to SYSMOD for its computations. The annual groundwater exchanges between the three subbasins of Central, East and West used in SYSMOD are shown in *Figures 26-28.* The west subbasin provided water to the other subbasin early in the analysis because the west subbasin was operationally prioritized and filled faster than the other two subbasins.

Figure 26: Central Subbasin Exchange

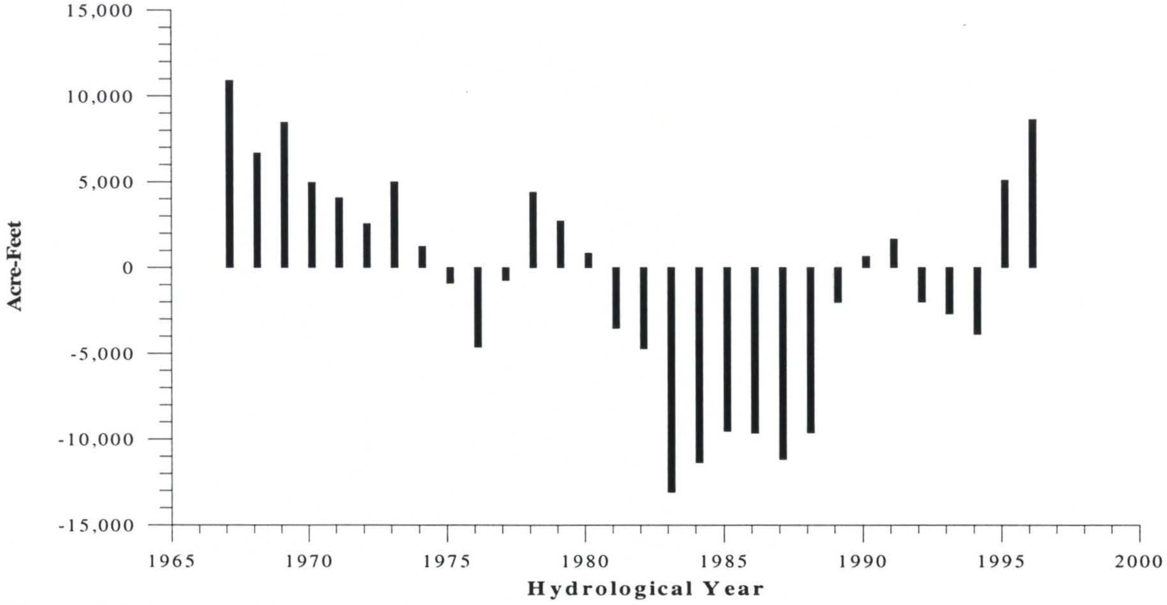


Figure 27: East Subbasin Exchange

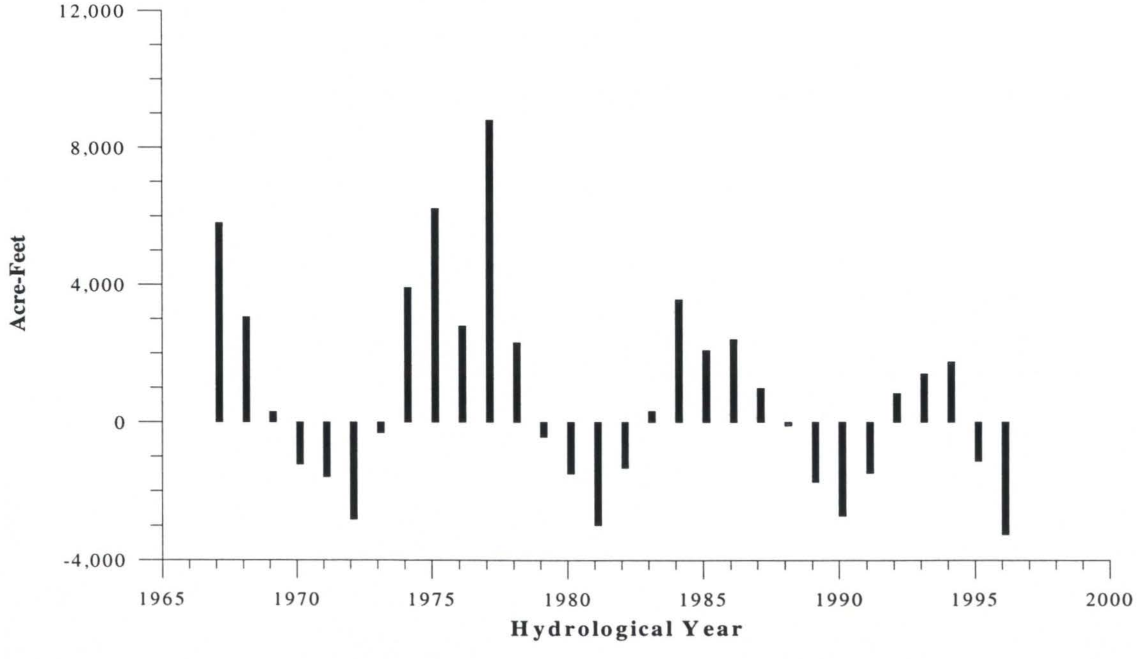
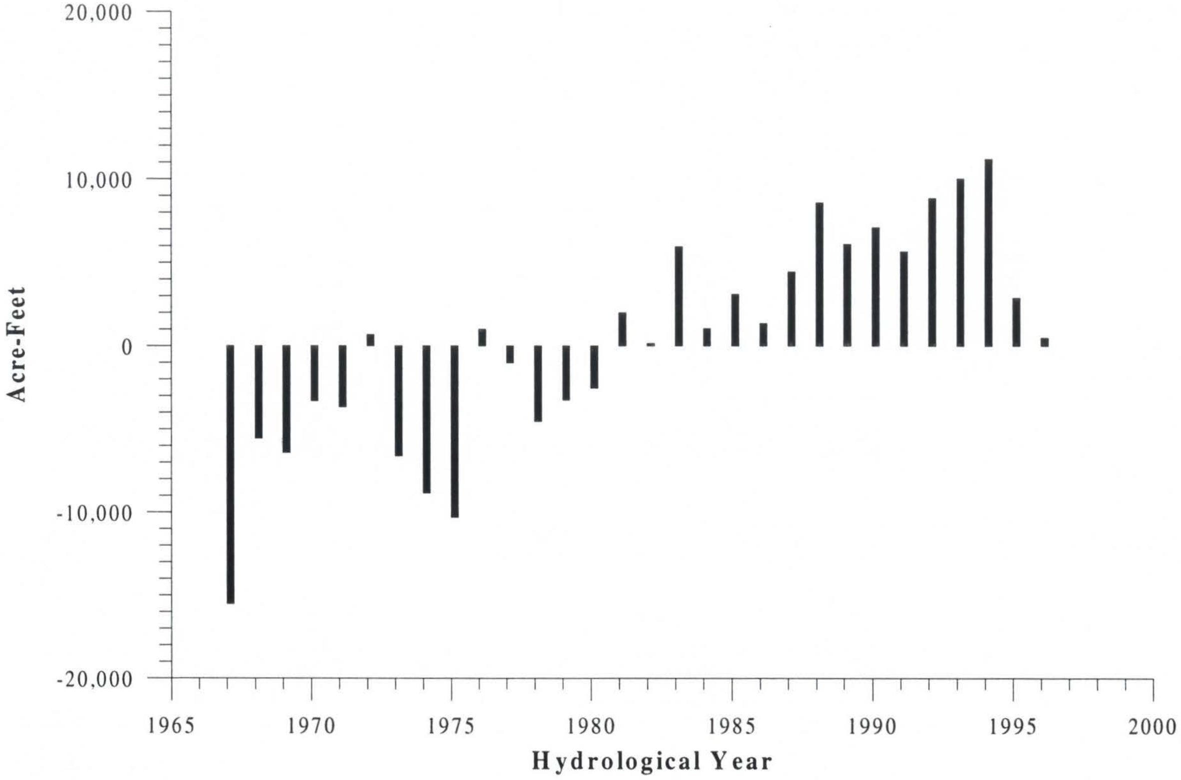


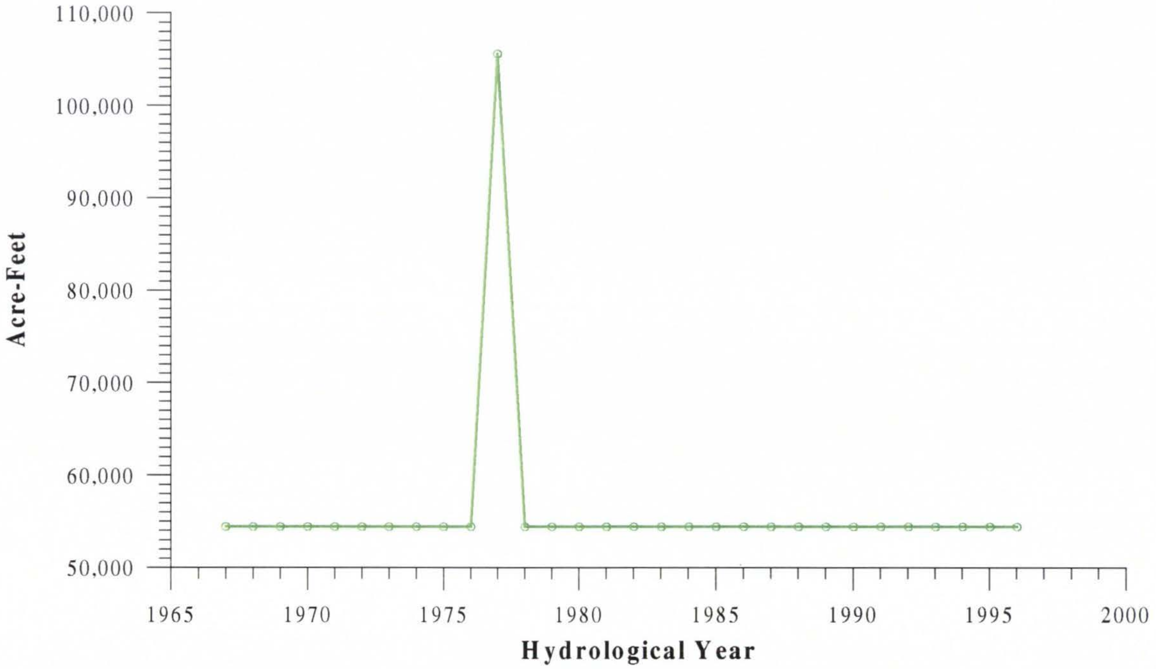
Figure 28: West Subbasin Exchange



The annual groundwater pumping in the subbasins are shown in the *Figures 29-31*. The maximum groundwater pumping occurs in 1977 for all of the subbasins.

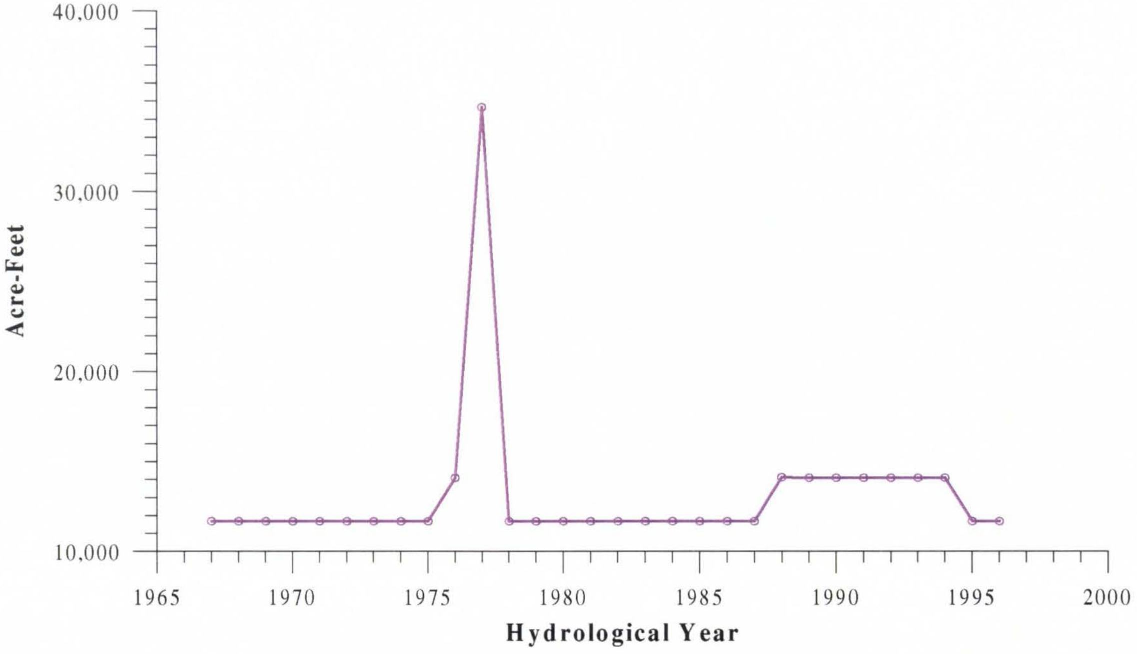
In 1977, the Santa Teresa Water Treatment Plant did not have water to deliver to the Central subbasin, and the subbasin water supply demands had to be met from groundwater pumping.

Figure 29: Central Subbasin Groundwater Pumping



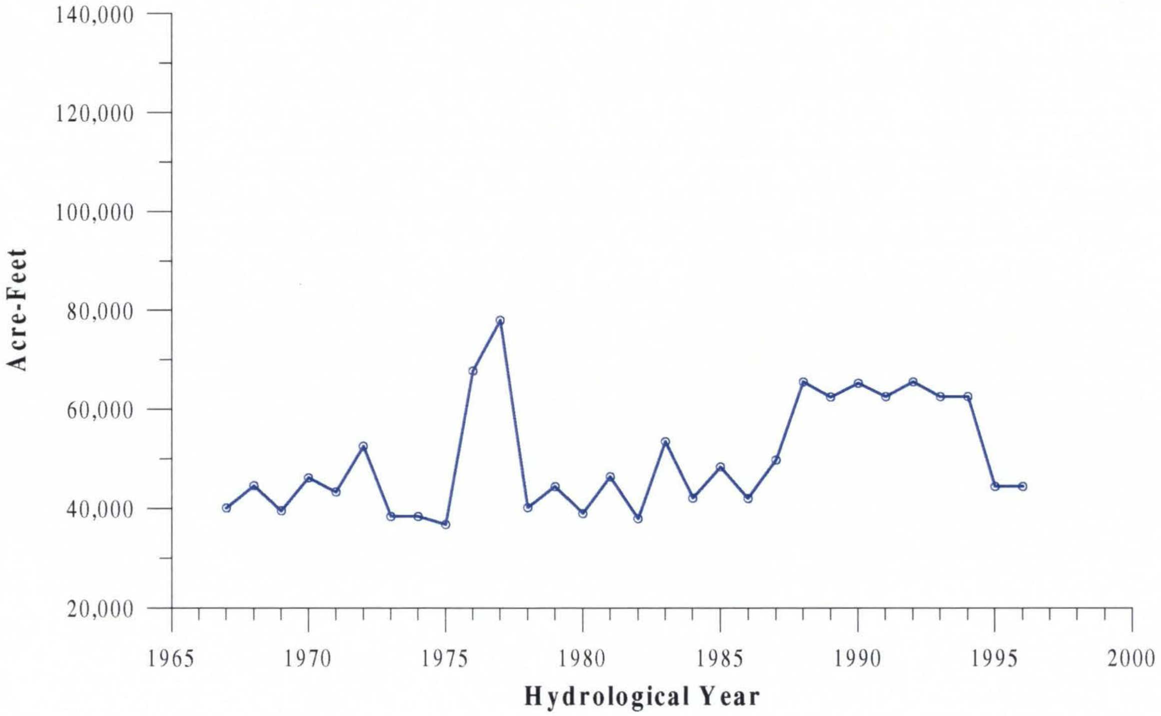
Santa Teresa and Penitencia Water Treatment Plants provide the treated water supply for the East subbasin. These two treatment plants did not have water to deliver to East subbasin in dry years. In addition, Hetch-Hetchy supplies some of subbasin's water needs and during the dry years this source was also cut back on its delivery. The basin had to make up the short falls in the surface deliveries by increased pumping as shown in *Figure 30*.

Figure 30: East Subbasin Groundwater Pumping



The Rinconada Water Treatment Plant, Hetch-Hetchy, and San Jose Water Company provide the treated water to the west subbasin. The deliveries from Rinconada Water Treatment Plant are prioritized to minimize the effects from fluctuation in deliveries from SJWC and cutbacks in Hetch-Hetchy supplies. The west subbasin met the shortfalls of San Jose Water Company and Hetch-Hetchy supplies.

Figure 31: West Subbasin Groundwater Pumping



The combined natural and artificial recharge for each of the subbasins and how they compared between the two models is shown in the *Figures 32-34*. During the dry periods water is not available for recharge and when the subbasin is full, recharge is curtailed.

Figure 32: Central Subbasin Total Recharge Comparison

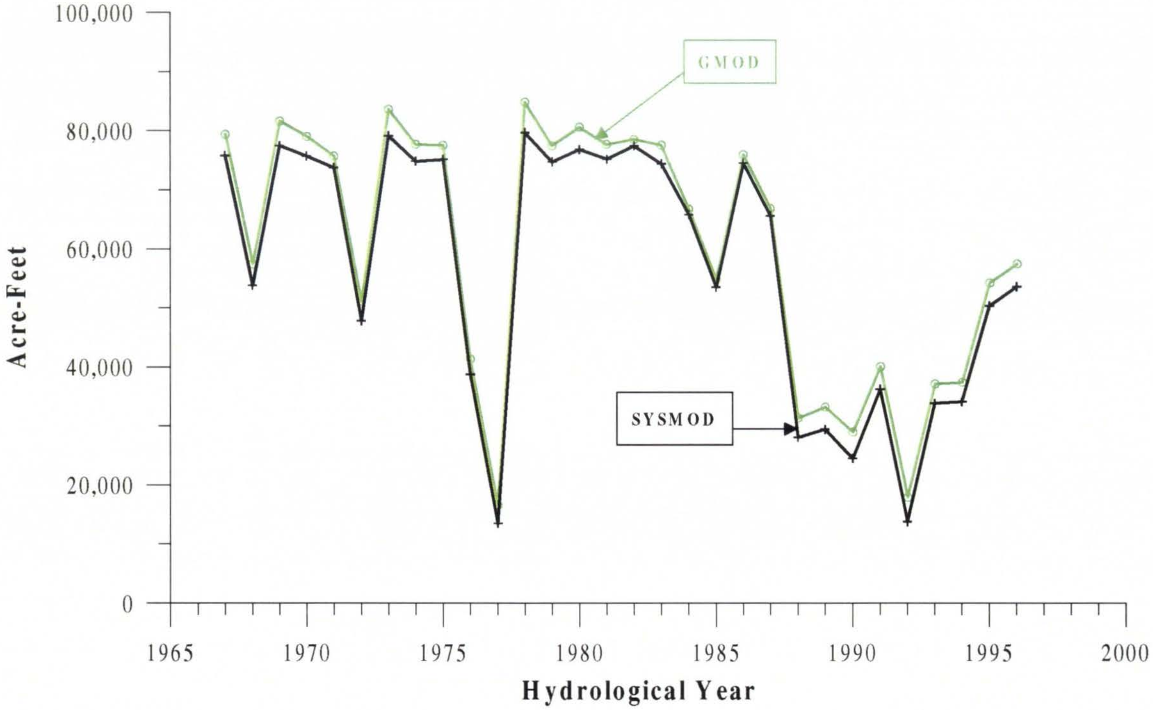


Figure 33: East Subbasin Total Recharge Comparison

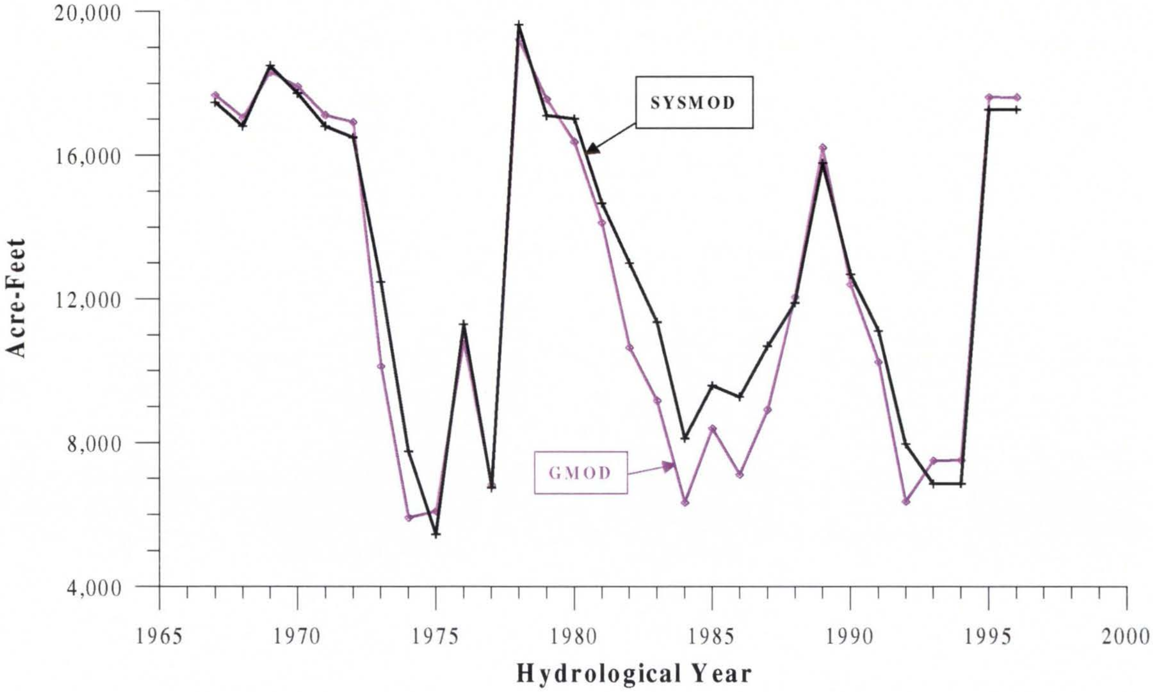
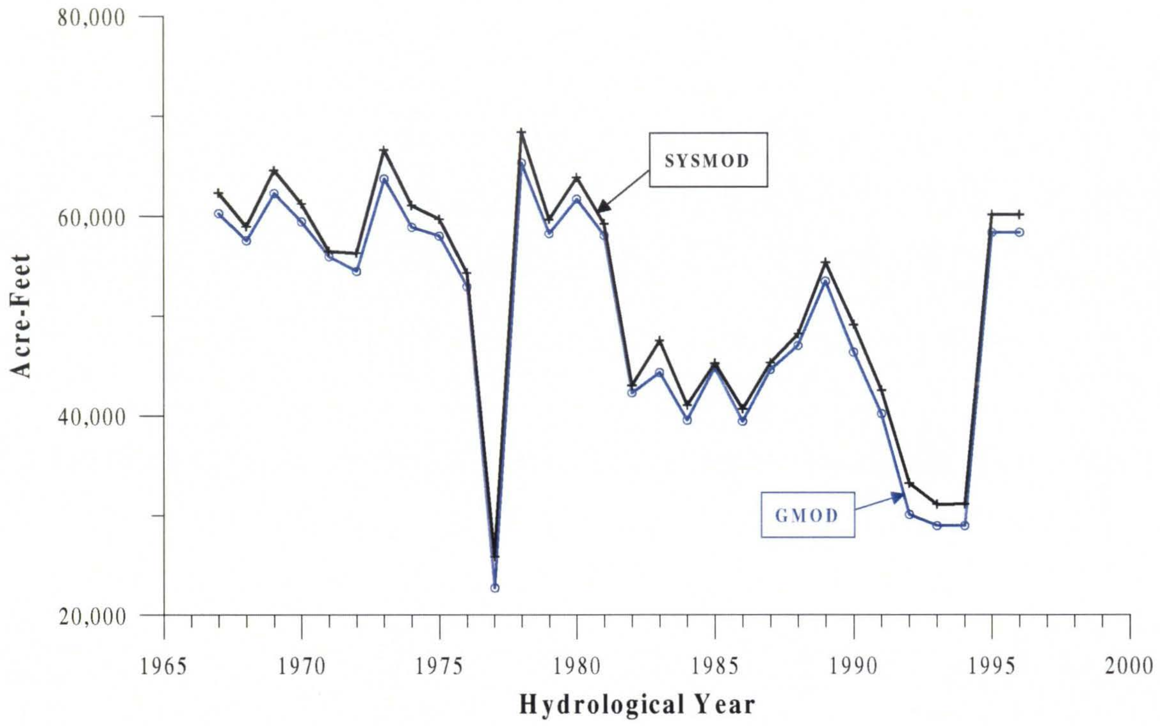


Figure 34: West Subbasin Total Recharge Comparison



The simulated groundwater storage levels for each of the subbasins is shown in the *Figures 35-37*. These figures also show small differences between the two models. Some of these differences are attributed to the differences in the distribution of recharge to each subbasin and the inter-basin exchanges between these subbasins in the two models.

Figure 35: Central Subbasin Groundwater Storage Comparison

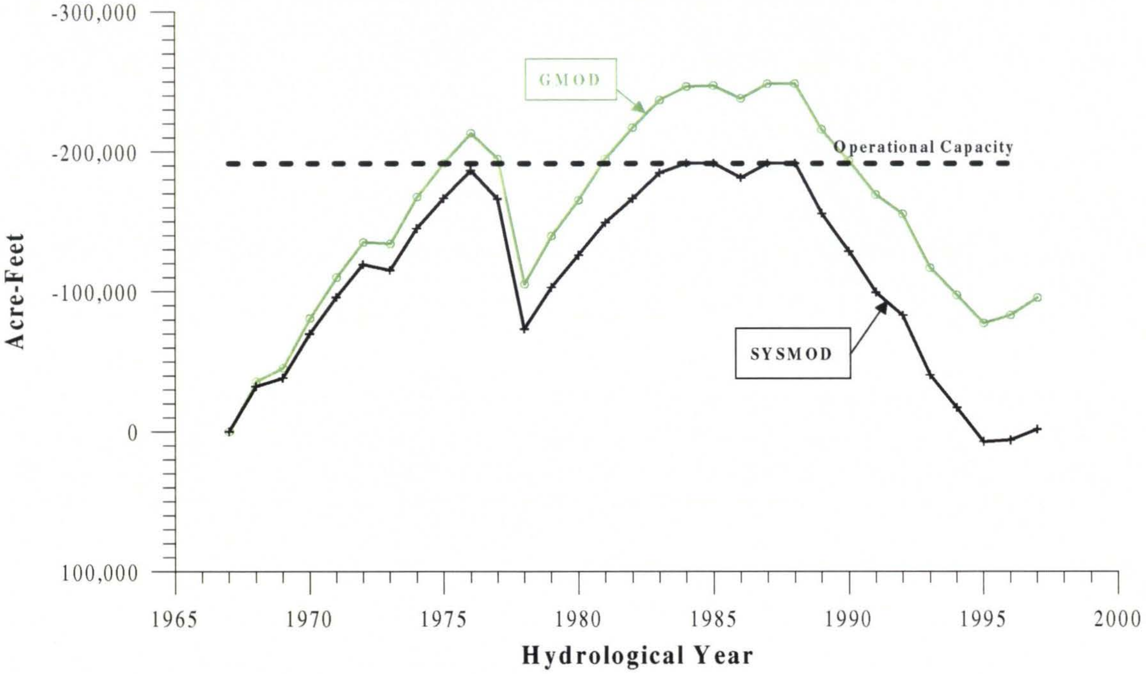


Figure 36: East Subbasin Groundwater Storage Comparison

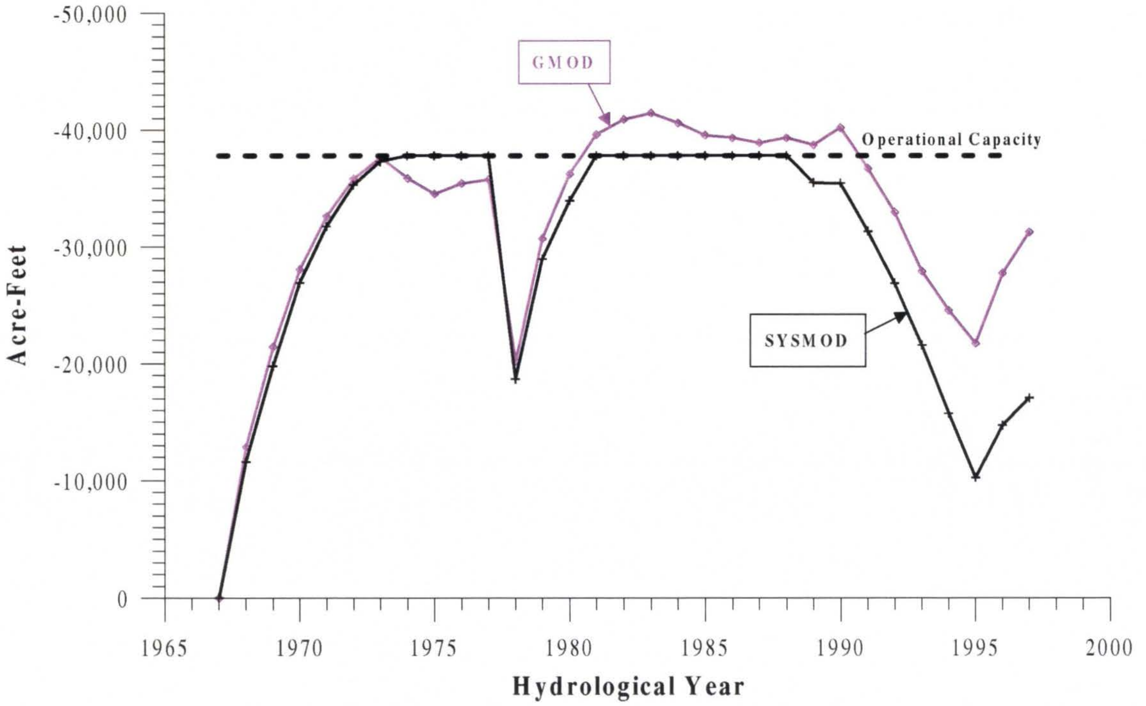
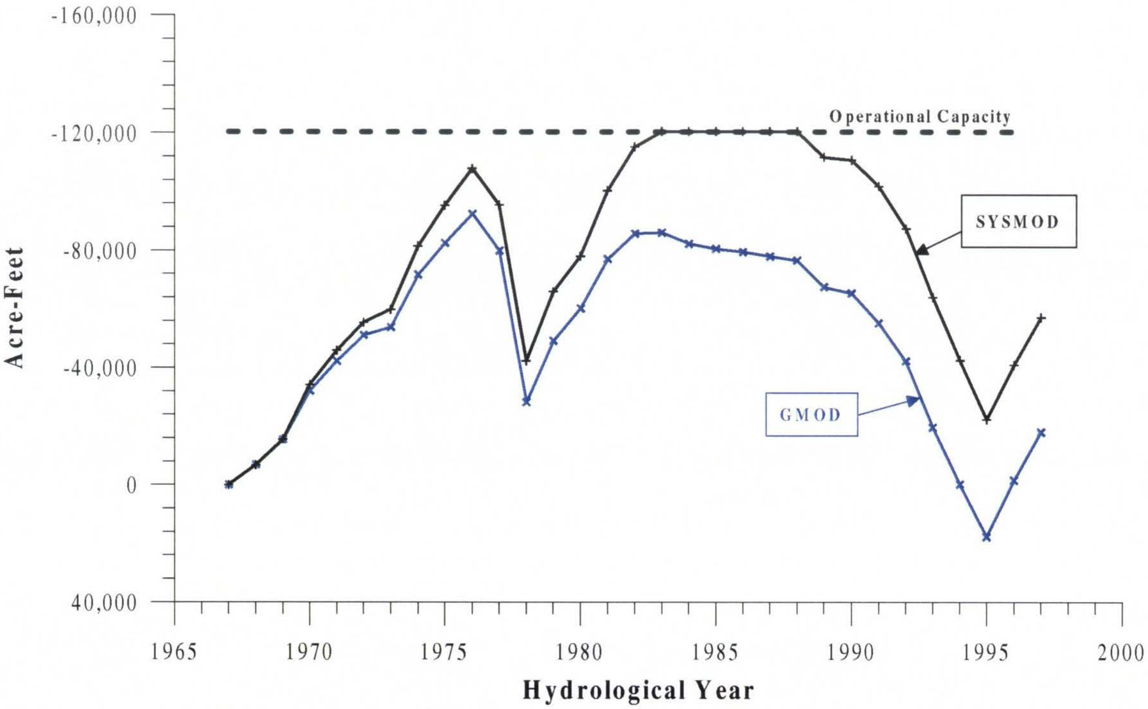


Figure 37: West Subbasin Groundwater Storage Comparison



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